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Modelling the Grand Banks Commercial Fishing Fleet: Fleet Structure, Fishing Performance and Economic Viability

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List of Abbreviations

AFPR - Atlantic Fisheries Policy Review; URL: www.dfo-mpo.gc.ca/afpr-rppa/home_e.htm

CBC – Canadian Broadcasting Corporation; URL: www.cbc.ca

CFV - Commercial Fishing Vessel

CPU – Central Procession Unit

DFO - Fisheries and Oceans Canada; URL: www.dfo-mpo.gc.ca

EEZ - Exclusive Economic Zone

NAFO - Northwest Atlantic Fisheries Organization; URL: www.nafo.int

MUNL – Memorial University of Newfoundland and Labrador; URL: www.munl.ca

NL - Province of Newfoundland and Labrador; URL: www.gov.nl.ca

OTP - Oceans To Plate

LOA - Length Overall

LP - Linear Programming

MIP – Mixed Integer Programming

TAC - Total Allowable Catch

TAGS - The Atlantic Groundfish Strategy

WB! – What'sBest!; URL: www.lindo.com

ZIFF - Zonal Interface Format Files

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Abstract

The Grand Banks commercial fishing industry has been faced with several crises in the past decades. These crises have included the major financial crunch and inflation of the late 1970s and early 1980s, as well as the resources collapse of the Northern cod stock and other groundfish stocks in the 1990s followed by the foreign fishing disputes of the mid 1990s. The thesis examines the evolution of the fishing industry in Atlantic Canada during these critical years with focus on the fisheries of the Grand Banks. A linear programming model of the configuration of the Grand Banks commercial fishing fleet is formulated to describe the post 2000 period. The model is driven using the results of an extensive analysis of historical records for this recent period. The model results are validated by comparing them with historical average annual data over the period 2000-2005. The linear programming model is run under several scenarios emulating changes in government policy and economic conditions affecting the harvesting sector. Based on the results, alternative fishing fleet configurations for the Grand Banks fishery are defined to improve the economic viability of the fishing fleet. The model pointed to changes in fleet configuration including a rationalization of the shrimp and crab fleets and a shift to longline vessels with higher-valued product for groundfish harvesting. Once implemented, these suggestions would advance the goals of the new "Oceans to Plate" approach to fisheries management recently announced by Fisheries and Oceans, Canada.

1 Introduction

The Grand Banks commercial fishing industry is an important sector of the economy in Atlantic Canada, particularly in the province of Newfoundland and Labrador (NL) where it contributes an estimated total labour employment of approximately 5,500 Person Years in harvesting and processing (Lane 2007). It is also historically significant considering that the seemingly endless abundance of fish in the area spurred the European exploitation of the fisheries in the 16^{th} century and the settlement of Newfoundland in the 18^{th} century (MUNL 1997). Therefore, due to the economic dependence of Atlantic Canada's coastal communities on the fishing industry, the groundfish resource collapse of the early 1990's has had a major negative impact, notably in Newfoundland. Faced with the reality of diminishing harvestable resources, the need for change in the commercial fishing fleet is evident and necessary in order to adapt to evolving circumstances.

In April 2007, the Minister of Fisheries and Oceans announced a new approach to the management of Canadian fisheries which have been plagued with long standing issues of overcapacity, low wages for many of its participants, major resource collapse, and management failures. This new approach, referred to as "Oceans to Plate" (OTP), involves all the participants in the seafood value chain, from the harvesting of the resource all the way to the consumer plate, in an attempt to create "a sustainable, economically viable, and internationally competitive industry" for Canada (Canada 2007e, http://www.dfo-mpo.gc.ca/media/back-fiche/2007/hq-ac17a-eng.htm).

OTP responds to the need to move the fisheries from economic dependence (as a result of the cost and resource crises of the past that have plagued the fisheries and even labelled the sector as a "social welfare activity") to a position of being economically viable. Inherent in this process is the shift from a supply to a demand-based, market-driven approach in order to extract greater value from sustainably managed resources and a decrease in harvesting capacity. The issue of overcapacity, i.e., the harvesting power of the entire fleet is greater than what the underlying resource can sustainably support, has been recognized repeatedly as one of the factors contributing to the poor economic performance of some of the segments of the harvesting sector. The objective of OTP is to improve the current situation by encouraging self-rationalization in the commercial fishing fleet so as to ensure its economic viability.

The goal of this thesis is to examine the recent performance of a key component of the commercial fishing fleet namely, the Grand Banks commercial fishery off the coast of Newfoundland. Since before John Cabot in the 15th century, fishing on the Grand Banks has been legendary (CBC 2006). Today, the Grand Banks fishery is a mere shadow of its former fishing prowess. The evolution of the Grand Banks fishery is examined in the context of the fisheries in Atlantic Canada since the 1970s to the turnoff the 21st century. The current performance of the fishery since 2000 is examined in detail from fishing records. A quantitative model of the fishery is constructed toward developing an improved economic performance of the modern Grand Banks fishing fleets and economic viability is investigated under various conditions. As such, this research investigates the ways and means of moving toward improved economic viability in the Grand Banks fishery in response to the Minister's call for more prosperity through OTP.

1.1 Research Question and Objectives

This thesis focuses on Canada's commercial fishing efforts in the geographical area of the Grand Banks off the east coast of Newfoundland within the 200-mile Canadian territorial waters boundary, corresponding to the Northwest Atlantic Fisheries Organization (NAFO) divisions 3L, 3N and 30, and excluding the identified areas of the "tail" and "nose" of the Grand Banks that are outside Canada's 200-mile exclusive economic zone (EEZ) (see Figure 1.1.1 and Figure 3.3.1).

The question this thesis poses is as follows:

In the context of DFO's Ocean to Plate approach, can the current configuration of the Grand Banks commercial fishing fleet be considered an efficient operation?

Our hypothesis is that the efficiency of the fishing fleet depends on how this is measured, e.g., as maximizing landed value, or net operating income, and is a function of key parameters for market value and operating costs. Moreover, it is the conjecture here that fleet efficiency can be improved through changes in its size and configuration, and that efficiency is impacted by exogenous changes to the operations of the fleet. The following objectives drive the process of providing results to support the hypothesis:

1) Derive a model of the Grand Banks commercial fishing fleet for the recent period.
2) Provide a detailed characterization of the Grand Banks fishing fleet through an extensive analysis of historical data and use those results as inputs to a quantitative, value-based model of the fishery.
3) Provide a mechanism for the analysis of alternative scenarios for costs, values, and fishing resources and their impacts on the economic viability and fleet configurations for the Grand Banks commercial fishing fleet.

After validating the model by comparing it with historical annual landed value data for the recent period, 2000-2005, alternative scenarios are defined corresponding to potential changes in government policy and economic conditions that may affect the Grand Banks fishery. The different scenario configurations are evaluated based on Net Operating Income for determining the best potential opportunities, fleet configurations, and fleet uses for improving the economic viability and the longer-term resiliency of the Grand Banks harvesting sector by fleet segments as a viable economic activity for the benefit of fishermen and all Canadians.

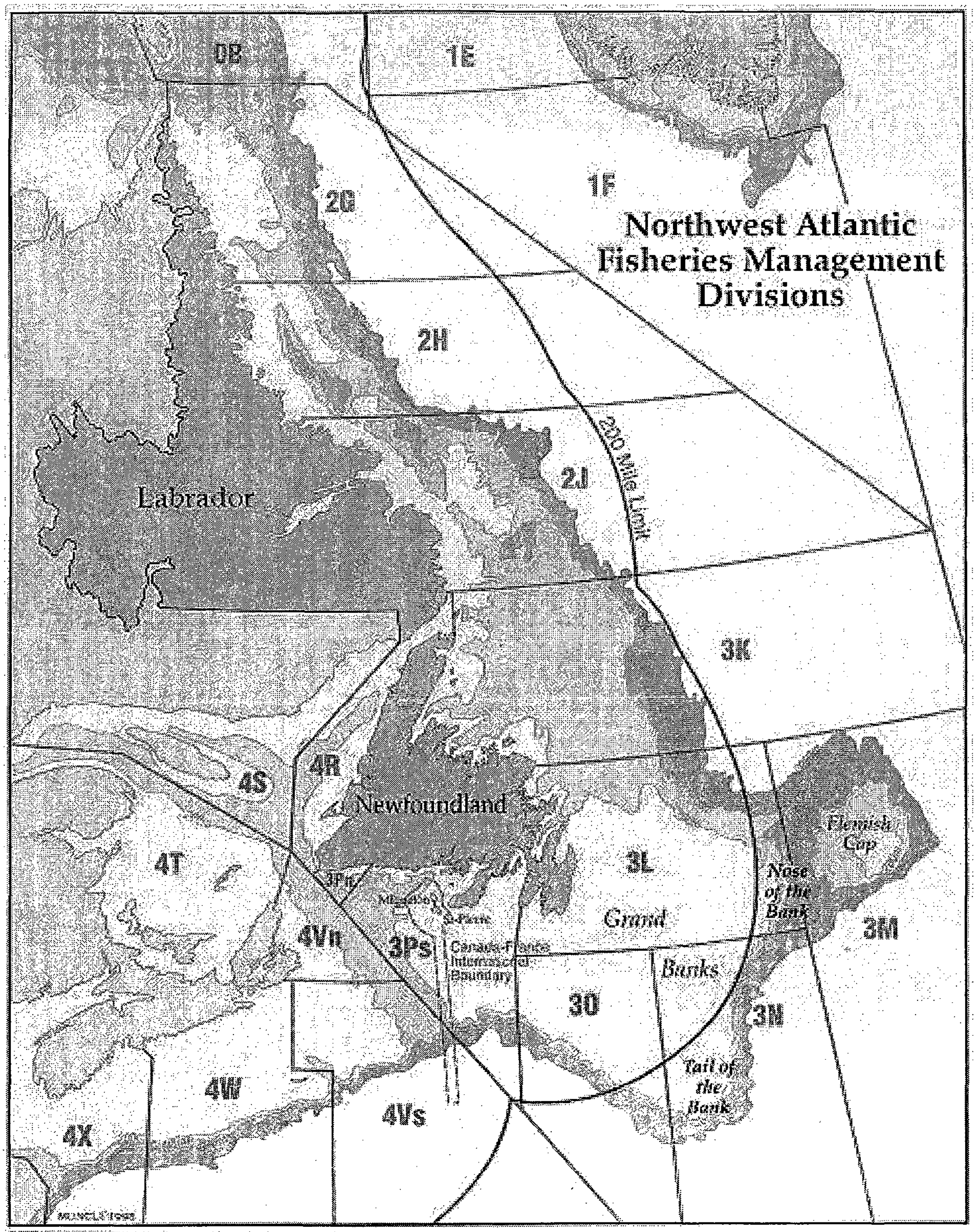

Figure 1.1.1 Map of NAFO Management Divisions (MUNCL)

1.2 Plan of the Thesis

This thesis is presented to describe the background, methodology, analysis and results of this applied research study in Systems Science. The thesis is presented in seven (7) chapters as well as an extensive appendix of data analysis and data description of annualized catch statistics.

As noted above, the current chapter, Chapter 1 introduces the subject of the thesis and states the key research objectives.

The first section of Chapter 2 offers a historical perspective of the Atlantic fisheries through a review of the relevant literature, emphasizing two key points, namely the financial crisis in the early 1980's and the groundfish resource collapse in the early 1990's. The literature review concludes with a look at the evolution of the fishery following the groundfish resource collapse and leading up to the ministerial announcement of the "Oceans to Plate" approach in April 2007 and its implications for the fishing industry. The second section of the chapter examines modelling methods used to solve fleet configuration problems optimally using Linear Programming (LP). The LP model is defined in detail in Chapter 3 and specifies the model for the case of the Grand Banks fishing fleet configuration problem.

Chapter 4 contains the data analysis of the Grand Banks fishing fleet with significant support from the extensive descriptive data analysis of the detailed Grand Banks catch data in the appendices.

Chapter 5 applied the results from the data analysis in the previous chapter to formulate the specific Grand Banks fleets LP models. This is followed by the process of model validation achieved through the comparison of the model's results with the information on actual statistics gathered in Chapter 4. The model is then analysed under a variety of defined scenarios in order to examine the potential impact of changes in economic conditions, such as increases in fuel costs.

Chapter 6 discusses the overall results of the model analyses and the implications for economic viability in the Grand Banks fleet.

Finally, Chapter 7 gives recommendations regarding the fleet configuration and modelling experience, and concludes the thesis with suggestions for future applied research in this area.

2 Background and Literature Review

This section is composed of three parts. This chapter presents an historical perspective of the Atlantic fisheries through a review of the relevant literature, emphasizing two key points, namely the financial crisis in the early 1980's and the groundfish resource collapse in the early 1990's. The review examines the evolution of the Atlantic fisheries, with emphasis on the Grand Banks, following the groundfish resource collapse and leading up to the ministerial announcement of the "Oceans to Plate" approach and its implications for the current fishing industry. The third section of the chapter examines modelling methods used to analyse fleet configuration problems.

2.1 The Fisheries

In the past few decades, two major crises have hit the Atlantic fisheries; the financial crisis in the early 1980's and the groundfish resource collapse in the early 1990's. Their gravity is reflected in the corresponding creation of respective government task forces defined by federal cabinet direction to deal with the problems in the fisheries.

The *Task Force on Atlantic Fisheries* was published its report in 1982 (Canada 1982). It is commonly referred to as the "Kirby Report" as noted below, after the name of its chairman, Senator Michael Kirby. The *Task Force on Incomes and Adjustment in the Atlantic Fishery*, headed by Richard Cashin, published its report in 1993 (Canada 1993). The Kirby report was written in a context of high interest rates, sharp increases in energy costs and high bankruptcy rates in the overcapitalized fishing industry. The Cashin task force was created in response to the notorious groundfish resource stock collapses that began decimating the groundfish fleets in Atlantic Canada since 1992. Although both task forces were created in response to different contexts, the similarities between their recommendations highlight persistent issues in the fishing industry. Overcapacity is an issue pervading the task force reports and the subsequent reports on the Atlantic fisheries mentioned above

The subsequent evolution of the Atlantic fisheries (post 1993) can be tracked through a progression of reports. In 1998, the Standing Committee on Fisheries and Oceans published a report on fisheries management issues and referenced The Atlantic Groundfish Strategy (TAGS) following public meetings with participants in the fishing industry in East Coast communities. In 2003, Vardy published a report on fisheries management in the province of Newfoundland documenting the evolution of the fisheries after the groundfish collapse (Vardy 2003). In 2004, the first phase of the Atlantic Fisheries Policy Review (AFPR) was published, entitled "A Policy Framework for the Management of Fisheries on Canada's Atlantic Coast", with the stated objective to "modernize the policy framework that governs how the Atlantic fisheries are managed." (Canada 2004b).

Many of the issues identified by both the Kirby and the Cashin task forces and documented in subsequent studies continue to plague the Atlantic fisheries to this day. The phrase stating that "the fisher[ies] today [do] not provide a good living for many people that participate in it". Written in 1982 (Kirby 1982, p.6) is still relevant today, and expresses the need for a new approach to fisheries management.

In April 2007, the Minister of Fisheries announced such a change - the implementation of the "Oceans to Plate (OTP)" approach to the management of Canadian fisheries (Canada 2007a). This policy will be analyzed in more detail below in the context of the *Canada - Newfoundland and Labrador Fishing Industry Renewal Discussion* paper that examines how OTP can be implemented (Canada 2007c).

The sections below begin by examining the conclusions of the Kirby and Cashin Task Force reports.

2.1.1 The Kirby Report

After the 3-mile territorial water limit was extended to form a 200-mile Exclusive Economic Zone (EEZ) in 1977, the Canadian fishing industry in Atlantic Canada sought to exploit its exclusive access to the resource by greatly increasing its capacity. This would later be characterized as the "boundless optimism associated with the implementation of Canada's 200-mile limit" (Canada 1993 p.15). The excessive increase in capacity, combined with high interest rates and increases in energy costs contributed to many bankruptcies and a fishery in "serious trouble" as stated by Michael Kirby in the preface to his report. This was "a disturbing paradox" due to easy access to a flourishing resource base and the substantial

United States' market for fish. The report focuses on groundfish and indicates that Newfoundland accounted for nearly half of the groundfish harvest.

The existing market conditions showed that in the 70s and early 80s close to 60% of Atlantic Canadian groundfish by weight was exported to the United States. Based on a study of the United States market, the Kirby Task Force advocated generic industry-wide advertising programs, an increase in the quality and the range of products offered, and an effort to reduce processing costs. The report notes that the slowness of the progression toward a market-driven approach was a major cause of the poor condition of fisheries in the early 80's. It is interesting to note the Minister of Fisheries and Oceans finally announced, two decades later, a change in their management principles to implement a market-driven approach two decades later.

When the Kirby report was written, scientific forecasts predicted increases in groundfish resources, especially cod. Therefore conservation was not a priority for the task force. The emphasis was put on the viability of the fishing industry and focused on industry restructuring. Unfortunately the exact opposite happened. Over the next decade, the groundfish stocks collapsed, which incited the moratorium on Northern cod in 1992 and the subsequent creation of the Cashin task force.

2.1.2 The Cashin Report

The Cashin report emphasized the fact that groundfish was the traditional foundation of the Atlantic fishery. The impact of the stocks collapse was felt most strongly in Newfoundland where the effect of the decrease in groundfish on the economy was multiplied because of its heavy processing requirement. Groundfish landings (approximately 250,000t annually), made up 80% of Newfoundland's catch with Northern cod accounting for one-third of the total groundfish catches before the collapse. This explains the major impact of the Northern cod's disappearance on the fishing industry.

The Cashin task force made recommendations concerning what strategies should be implemented in order to shift to a more sustainable fishery "both ecologically and economically", notably by matching harvesting and processing capacity to the resources once they were rebuilt. Unfortunately the stocks did not rebuild as expected. Northern cod stocks remain depleted today with no signs of rebuilding.

2.1.3 Subsequent Reports

The lack of recovery of the groundfish stocks after the recommendations of the Cashin report were released led to the production of subsequent studies on the Atlantic fisheries.

The East Coast Report was published in 1998 after the Standing Committee on Fisheries and Oceans visited fishing communities on the East Coast of Canada in the fall of 1997 (Canada 1998). The report highlights the continued impact of the groundfish resource collapse at a time when the program put in place to help people affected by the collapse was about to end. The report also mentions a sentiment of unfairness expressed by witnesses during the hearings with regards to the attribution of quota and allowed bycatch to foreign fishing vessels, as was the case with the legal bycatch of Northern cod in the Greenland Halibut quota in NAFO area 3L. Most of the witnesses said they felt the federal government had failed to meet their responsibility to manage the fishery.

The Vardy report focuses on management issues within Newfoundland and Labrador, yet points once again to overcapacity as a contributing factor to the poor performance of the fishing industry. The Vardy report also highlights the lack of clear management objectives for Fisheries and Oceans Canada (DFO) and analyses the problems arising from having the two main components of the industry; harvesting and processing, under federal jurisdiction and provincial jurisdiction respectively.

When the Atlantic Fisheries Policy Review (AFPR) was launched in 1999, the adjustment programs put in place to assist fishers affected by the groundfish collapse, as recommended in the Cashin report, had ended. In addition, there were still "Many fleets ... simply too large given the availability of resources" (Canada 2004b) in spite of capacity being reduced in the 1990's through federally funded license buyouts and an early retirement program.

Another issue addressed by the AFPR was in regard to (i) the owner-operator policy and (ii) the fleet separation policy introduced in 1979. The first applies to "fishing vessels less than 65' (19.8m) in length and requires that the licence holder personally fish the licence". The second "applies to fishing vessels less than 65' in length and separates the harvesting and processing sectors. It does not recommend the issuance of new inshore licences to corporations, including processing companies". To circumvent the fleet separation policy and owner-operator policy, trust agreements have been used to privately transfer the benefits of holding a license from licence holders to a third party or a corporation. Generally, a trust agreement is signed between a participant in the harvesting sector and a person or a corporation from the processing sector. The trust agreement, a legally binding contract, is used by the fish harvester as a source of capital, and by the fish processor or processing company to control the source of its inputs. The fish harvester holds the license in trust and the fish processor effectively owns the license. Although not illegal, these agreements were not condoned by the DFO because they contravened the policies mentioned above. Measures were put in place in 2007 to preserve the independence of the inshore fleet and eliminate most trust agreements (Canada 2007i).

2.1.4 Oceans to Plate

Although the term "Oceans to Plate" was only recently coined, the idea of a market-driven approach based on consumer demand is not new, as we can see in the following quote:

> "The demands of the consumer must always continue to dictate the form in which fish are marketed. Consumption always regulates sales, and sales regulate not only production but the particular form of the product".
>
> Report of the Royal Commission on the Maritime and Québec Fisheries, 1928. (In: Canada 1982, p.49)

In 1976, a government policy paper states that "... strategies adopted reflect a fundamental redirection in the government's policy for fishery management and development [from] protection of the renewable resource [to a] more direct intervention by the government in controlling the use of fishery resources, from the water to the table" (Canada, 1976 in:

Parsons, 1993, p.26). Parsons notes that the "Reference to 'direct intervention by the government in controlling the use of fishery resources, from the water to the table' has a parallel in the recent policies labelled as 'oceans-to-plate'".

The concept is again mentioned, albeit implicitly, in the Kirby report, stating "The fishery is a process by which fish are moved from the sea to the dinner plate of a consumer" (Canada 1982). At one end is the resource, at the other the market, with "a troubled fishing industry" in between that has failed to make the links work in a way that benefits everyone's economic interests.

Seventy-nine years after the Royal Commission's report was published, the announcement of a "new approach" to the Canadian fisheries by the Minister of Fisheries on April 12, 2007 indicated the application of OTP principles to the management of the fishing industry. This new approach addresses the issue of what Kirby called "a chain with too many weak links."

Essentially, the OTP approach is one in which the resource is harvested from the ocean, processed, marketed and sold in a way that meets the demands of the final link of the value chain, the consumer, with an aim to "extract optimal value from world markets" (Canada 2007a), through a sustainable and resilient industry that can adapt to change. The OTP approach also aims to create an industry that attracts and retains skilled workers and provides attractive incomes for its participants.

The Canada – Newfoundland Fishing Industry Renewal Discussion Paper (Canada 2006b) is so far the main document discussing how the OTP approach can be implemented. This paper also signals a greater cooperation between the two levels of government (federal and provincial) as is necessary for this new integrated approach.

However, the OTP approach implies an integrated method of fisheries management that includes the potential vertical integration of fish harvesting and processing, which is currently not permitted in the inshore fishery being inconsistent with the concept of "fleet separation". Furthermore, the ministerial announcement of a new approach to fisheries management includes measures to eliminate trust agreements and strengthen the independence of the inshore fishery while allowing flexibility "for those fleets who have [...] become significantly vertically integrated".

The ministerial announcement regarding OTP was followed by DFO policy changes as a result of the implementation of the OTP approach. For the harvesting sector, these policy changes include modifications to the vessel replacement rules through the elimination of cubic volume restrictions, the creation of three vessel classes in order to allow for flexibility, and new rules to allow for the merging of fishing enterprises, all of which attempt to rationalize the current capacity of the fleet (Canada 2007d).

This thesis focuses on the implications of the OTP approach for the harvesting sector of the Grand Banks fisheries. We interpret OTP as implying the following objectives for the Grand Banks commercial fishing fleet:

- Sustainably extract greater value from fish stocks
- Move toward a more resilient and economically viable fleet

2.2 *Fleet Evolution*

The fishing industry has gone through deep economic and ecological crises in recent years. The following section examines how the commercial fishing industry has evolved and what impact these crises have had on the fishing fleet, followed by an examination of the current fleet configuration.

Historical fleet capacity can be traced from data detailing the number of registered vessels by size and by region in Atlantic Canada. There is a marked fluctuation in the total vessel numbers from 27,682 in 1983 to 30,390 in 1989, after which the numbers started decreasing steadily to reach a low of 19,684 in 2002. This decrease is mainly due to the number of vessels under 35'(10.7m) decreasing from 22,499 in 1988 to close to half that number, 11,750, in 2002. Between 1983 and 2002, in the greater than 35' and less than 65' (19.8m) vessel classes, the numbers are fairly stable with only small fluctuations. The vessels of overall lengths between 65' and 100' (30.5m), experienced declining numbers from 123 in

1983 to 81 in 2002. Large vessels over 100' showed dramatic declines from 186 in 1993 to a low of 80 in 1995. These declines reflect the impact of the moratorium on Northern cod, the impact of which effected the number of vessels registered in Newfoundland in particular, which started with 74 in 1993 dropping to 40 in 1994 and 13 in 1995, increasing to 28 in 1996 and then stabilizing in the low 20's. The total number of large vessels over 100' for the whole Atlantic region increased slightly after 1995 to reach 102 in 2002 (Canada 2005).

In the Canadian Fisheries Statistics report for 2004, the number of active vessels based on province of landing declined between 2002 and 2003 from 6 268 to 5 949 to increase back up to 6 226 in 2004, making up 37% of the total number of active fishing vessels in Canada that year (Canada 2007h) .

In the Canadian Fisheries Statistics report for 2004 mentioned above, four major commercial marine fishing fleets are listed for the Newfoundland and Labrador region which includes the specific area of interest in this thesis. They are:

(i) the inshore fleet- comprised of vessels under 35', with snow crab and lobster accounting for \$60M and \$18M of the \$110M total landed value respectively;
(ii) the nearshore fleet- vessels between 35' and 65' landing \$217M worth of snow crab and \$60M of shrimp out of a \$319M total landed value;
(iii) the midshore fleet - with \$1M landings of snow crab out of a \$6M total; and,
(iv) the offshore fleet - made up of vessels over 100' in length, harvesting \$60M worth of shrimp with a total \$111M landed value for all species. These figures indicate a shift away from groundfish and toward the abundant shrimp resource and the lucrative snow crab and lobster (invertebrate species) harvests.

A recent DFO internal report gave the following information regarding the economic viability of the fishing fleet within the Canadian portion of the Grand Banks, our geographical area of interest (Lane 2007):

- The small (under 65') mobile and fixed gear vessels are considered to be economically viable.

- The mobile gear fleet is viable because of the availability of the shrimp resource, and the fixed gear fleet because of the lucrative crab resource.
- Both the mobile and fixed gear vessels of medium size (from 65' to under 100') appear not to be economically viable.
- The mobile gear fleet is only made up of a few remaining vessels, and its inability to take advantage of the shrimp resource is the main reason for not being viable.
- Large vessels appear to be viable, mainly because of a decrease in the size of the fleet.

The recent evolution of the commercial fishing fleets describes a sector in flux. The inherent uncertainty of fisheries resources, the wide fluctuations in global fisheries markets, and the stark reality of the international economic crisis do not provide a clear direction for fleet evolution toward economic viability. In the following section a model of the commercial fishing fleet for the Grand Banks is presented as a means to examine and configure the fishing fleet with the objective of achieving improved value for the industry and for fishermen.

2.3 Fleet Configuration Modelling and Optimization

The following section begins with an examination of optimization problems in general and continues with a look at modelling fishing fleet configuration in particular.

2.3.1 Optimization problem

Winston's well-known *Operations Research* textbook, mentions that the popular mathematical programming technique of Linear Programming (LP) has been used to solve optimization problems in a variety of industries including banking, petroleum and trucking (Winston 1994). LP is a mathematical optimization procedure that determines an optimal decision strategy represented by variables whose values are limited by constraints imposed on the problem at hand. A feasible solution consists of decision variables values that meet the constraints, and an optimal solution maximizes or minimizes a linear function of the decision variables depending on the type of problem, e.g. minimize costs or maximize revenue.

Dantzig, one of the founders of LP, published the Simplex method used to solve linear programming problems and made extensive use of linear programming to solve optimization problems. For instance LP was used to configure the size of a fleet in *Minimizing the Number of Tankers to meet a fleet schedule* (Dantzig 1954). The LP associated with this example is solved by hand using the Simplex method.

A Computational Study of a new Heuristic for the Site-Dependent Vehicle Routing Problem (Chao 1999) is another example of Linear Programming. In this paper, a heuristic is presented that uses an LP model for routing a heterogeneous fleet of site-dependent vehicles servicing customers with different requirements regarding vehicle types. Computational results are given for a set of 23 test problems. Each set contains 27 to 199 customers, with a maximum of 12 vehicles available for each of the three types (small, medium and large) of vehicle. Central Processing Unit (CPU) times range from 1.65 seconds for the smallest and 2,297.32 seconds for the largest problem on a 166 MHz Pentium PC using the MPX package.

More recent examples of LP include *Weekly airline fleet assignment with homogeneity* (Bélanger et al, 2006) where the goal is to assign different aircraft types to each leg of an airline's scheduled flights so as to maximize profits while meeting availability and routing constraints. A penalty is added when different (heterogeneous) aircraft types are assigned to the same flight operated on different days of the week, since homogeneity is preferred for improved customer service and operations planning. This paper presents a two-phase heuristic solution and compares computation time with that of the direct Mixed Integer Programming (MIP) solution. CPU time is significantly reduced with the two-phase heuristic presented in the paper. Below are the characteristics of the two sample problems used in the paper:

- (i) Between 32,000 and 45,000 variables
- (ii) A Central Processing Unit (CPU) time between 750 and 76,159 seconds for the direct MIP approach and between 1,250 and 23,229 seconds for the two-phase heuristic on a SUN Ultra 10/440 workstation (Greater CPU times for both solutions are a consequence of higher penalties on heterogeneity)

Another example is *Heuristics for Large Scale Labour Scheduling Problems in Retail Sector* (Zolfaghari et al. 2007), in which LP is applied to an employee-scheduling problem. In the example given in the paper, the large number of potential employee shifts results in a problem with close to 4.5 million decision variables. The paper gives a set of heuristics that can be used to reduce the number of potential shifts before optimization is applied. When applied to a small employee-scheduling model, the heuristics greatly decrease the number of potential shifts generated and, as a result, the number of decision variables in the optimization problem. The 567 decision variables related to all potential shifts are reduced to a number between 24 and 67 depending on which heuristic is applied. Results show that computing efficiency is greatly improved while the quality of the solutions is not compromised.

2.3.2 Fishing Fleet Configuration Modelling

The configuration of a fishing fleet can also be viewed as an optimization problem. In the case of the commercial fishing industry in Atlantic Canada, E. D. Gunn and collaborators propose several optimization models. An example of this is *Planning harvesting and marketing activities for integrated fishing firms under an enterprise allocation scheme* (Gunn et al 1991), This paper models an integrated groundfish harvesting and processing company. Its goal is to maximize the company's net revenue using a large-scale linear programming model. Gunn applied this type of modelling to identify improvements in the operations of a large Atlantic seafood company, National Sea Products (now known as Highliner Fine Foods of Lunenburg, Nova Scotia) (Gunn 1985). This fleet fished alongside Newfoundland fishermen for offshore groundfish on the Grand Banks prior to the collapse of the Northern cod stock. In the LP problem related to this example, the limited computer resources available requires the linear aggregation of time periods, then disaggregating the solutions into twelve one-month period to significantly reduce the 59,940 decision variables present in the full-blown problem. The resulting LP's have following characteristics:

- (i) Between 5,544 and 11,304 variables; 882 and 2,399 constraints.
- (ii) A Central Processing Unit (CPU) time between 1,706 and 6,487 seconds on a VAX 785 Computer using the MPX package.

Another example is the use of Mixed Integer Programming (MIP) in *Dispatching a fishing trawler fleet in the Canadian Atlantic groundfish industry* (Gunn 1992) the aim of which is to dispatch a trawler fleet owned by an integrated fish-processing company in a way that minimizes costs while meeting the input requirements of the processing plants. Two MIP models of this problem are presented and solved using a two-phase algorithm and the results show that the models can help to improve the operations of the trawler fleet. The test problems related to this example have the following characteristics:

- (i) An estimated 13,320 decision variables
- (ii) An average total CPU time under 5 seconds for the two-phase algorithm.

LP has also been used previously to solve a related problem in *Bioeconomic modelling of the fisheries of the English Channel* (Pascoe 1998). Pascoe's objective is to use a linear programming model of the English Channel fishing fleet to help examine the impact of decision-making on the economic status of its participants and the biological component of the fishery with the intention to use it as an input in the management of the fisheries.

The use of LP in the determination of fishing fleet configuration and activities is well-documented. This research extends these applications to determining fleet configurations for improving valuations in the specific case of the Grand Banks fishing fleets including inshore, offshore, small and large vessels. LP provides the best analytical approach to consider this based on the fleet's Net Operating Income.

2.3.3 Solution Methods

LP formulated models can be solved by a number of different approaches. The large scale problems of Gunn et al used structured formulation methods and the XMP package to solve these problems. In his 2007 survey of LP software available, Fourer notes that many LP packages support 64-bit and multi-processor computing that are now available in personal computer systems, and allow unlimited number of constraints and variables. Some are also provided as add-ins to spreadsheet software to facilitate development and taking advantage of advanced spreadsheet formulas.

The use of a spreadsheet is a convenient way to enter the data corresponding to our LP. The standard solver available in Microsoft® Excel® has a limit of 200 decision variables and is insufficient for the size of problem to be treated in this work. The formulation of the Grand Banks fleet configuration problem requires approximately 7,000 decision variables and 3,200 constraints. Thus, the current problem requires an advanced LP solver. In this thesis, the LP solver adopted What'sBest! Professional (LINDO 2009), an Excel® add-in that has limits on the number of decision variables and constraints large enough for the size of our LP model.

The following chapter describes the LP modelling methodology to be applied to the Grand Banks fishery fleet configuration toward improving the fleet's economic performance.

3 Methodology

This chapter presents the methodology for constructing a model for the analysis of the performance of the Grand Banks commercial fishing fleet for the post groundfish moratorium period (after 1992) using the latest available data from the new millennium, 1995-2005.

3.1 Linear Programming Formulation

This thesis follows the description in the literature review in Chapter 2 above regarding mathematical programming methods to optimize the economic performance of the Grand Banks fishing fleet. The methods described here build on related work that has been done in analyzing and improving fleet performance. The current methods provide a perspective for the entire Grand Banks fishing fleet toward maximizing the fishing yields from operations given the recent exploitation levels of the fleet. Linear programming (LP) is used as the methodology to develop this analysis. This chapter presents the LP formulations designed to achieve maximal economic performance in the current period developed for the separable fishing fleets of the Grand Banks.

Simply put, LP problems are composed of: (i) decision variables, (ii) a single-valued objective function, and (iii) a set of constraints. In the Grand Banks model, the decision variables represent the effective number of average vessels in each identified class. The objective function is the expression to be optimized and represents either the total operating revenue of the fleets, or the net operating profit of the fleets. The objective of either function is to maximize. The model includes catch constraints, i.e., the limited catch by location and time period for each species prosecuted, and restrictions on the fleet size and the allowed period of operation for each vessel class. The data for the LP formulations (periods, locations, fleets, objective function coefficients, catch limits, and fleet sizes) are derived from detailed historical data on individual reported catches by vessel obtained from Fisheries and Oceans, Canada, Policy Sector. The detailed of these data are analyzed in Chapter 4 of the thesis. The following section describes and illustrates the LP model formulations for the Grand Bank fishing fleets.

3.2 Model

This subsection presents the general LP model formulation for the economic performance of the Grand Bank fishing fleets. Table 3.2.1 below lists the variables, constants and indices used in the model formulation, and Table 3.2.2 specifies the inputs to the model with respect to catch and fleet size.

Table 3.2.1 Variables, Constants and Indices

Category	Name	Symbol
Decision Variables	Number of Vessels	N
Constants	Operating Cost per unit vessel	c
	Nominal Revenue (landed value per kg of fish)	r
	Weekly Catch per Vessel (kg)	a
Indices of Decision Variables And Constants	Time (weeks)	*t*
	Location (NAFO subdivisions)	*l*
	Species	*i*
	Gear	*j*

Table 3.2.2 Limit Catch and Fleet Size Specifications

Name	Symbol
Total Catch by species, gear type and location	L_{ijl}
Total Catch by species, gear type and time period	L_{ijt}
Total Size of fleet by species, gear type and location	S_{ijl}
Total Size of fleet by species, gear type and period	S_{ijt}

As stated in the previous section, LP problems are composed of decision variables, a single-valued objective function, and a set of constraints. The decision variables are defined as follows: Let N_{ijtl} denote the number of vessels deployed for species *i*, using gear type *j*, in week *t* and zone *l* where $i = 1,\ldots,N_s$ $j = 1,\ldots,N_g$ $t = 1,\ldots,52$ and $l = 1,\ldots,N_a$

The LP objective function is as follows:

$$\text{Max} \sum_l \sum_t \sum_j \sum_i (r_{ijtl} \cdot a_{ijtl} - c_{ijtl}) N_{ijtl}$$

Where r_{ijtl} is the landed value per kg, a_{ijtl} the catch rate per unit vessel and c_{ijtl} the operating cost (fuel, labour, provisions, bait and ice). Unit operating costs also vary by species for some vessels that fish multiple species. In general however, operating costs are gear dependent.

The objective function is subject to the following linear constraints:

Limited catch by species, gear type and location	$\sum_t a_{ijtl} \cdot N_{ijtl} \le L_{ijl}, \forall i, j, l$
Limited catch by species, gear type and time period	$\sum_l a_{ijtl} \cdot N_{ijtl} \le L_{ijt}, \forall i, j, t$
Fleet size upper bound by species, gear type and location	$\sum_t N_{ijtl} \le S_{ijl}, \forall i, j, l$
Fleet size upper bound by species, gear type and period	$\sum_l N_{ijtl} \le S_{ijt}, \forall i, j, t$
Nonnegativity constraint	$N_{ijtl} \ge 0, \forall i, j, t, l$

Each decision variable in the objective function represents the number of fishing vessels active for each combination of area, time period gear type and species. Active fishing vessels exert a given level of average fishing effort that is expected to result in an average fishing yield. In the model, the number of fishing vessels are defined as continuous decision variables, i.e., when the value of the decision variable is not an integer, it represents a portion of that time period's average level of fishing activity and fishing yield. For instance a value of N=0.75 represents one vessel active for three-quarters of the time an average vessel would be during the specific time period in question.

3.2.1 Separable Fleet Segments and Model Subsets

The LP formulation described above maximizes the Net Operating Income of the entire Grand Banks commercial fishing fleet. The characteristics used to define the fleet are based on species, gear type, location and time period combinations. It is therefore possible to separate the model into smaller subsets of the decision variables corresponding to specialized fleet segments provided the sets of constraints for these variables are independent for each of these segments. Since the constraints on catch weight limitations and fleet size are regulated by species and according to specialized gear types separately, then such separation is possible and efficient for computational purposes, i.e., the LP solutions for separable fleet components reduces the overall size of the LP formulation for the entire Grand Banks fleet which exceeds 13,000 decision variables and 5000 constraints. Separating the Grand Banks fishing fleet into segments will result in LP models of more manageable size. The derivation of the fleets is determined from the analysis of the extensive catch by vessel data described in detail in Chapter 4 and the fleet segments are defined in Table 5.1.1.

3.3 Example

This subsection illustrates the LP model formulation derived for the Grand Banks for one of the separable fleet components, namely, the catch of the pelagic (schooling) species, capelin that is caught via specialized fishing gear unique to that species. The LP model formulated for capelin below is presented to demonstrate the similar problem formulations for the remainder of the Grand Banks separable fishing fleets described in Chapter 4 below. Chapter 4 details the data parameters for the LP models for all fleets.

The example below presents a subset of the final model for one species, capelin. Capelin is harvested over seven weekly time periods each year (weeks 26 through 32), and is fished in three separate locations, designated as NAFO subdivisions 3La, 3Lb and 3Lf (see also Figure 3.3.1). Data for the capelin fishery is derived from the annual catch by vessel (ZIFF) dataset provided by Fisheries and Oceans, Canada. Annualized data are examined over the years 2000 to 2005 and averaged annually over this period for use as data in the capelin LP model parameter set (as per Table 3.2.1 and Table 3.2.2 above).

In order to compare the results of the model with average historical data over the planning period, year 2000 to 2005, the LP model is run for the case c = 0, i.e. when operating costs are equal to zero. Thus, the LP objective function returns the maximizing revenue for capelin as a function of the deployment of the capelin gear fleet into the locations and periods of that fishery. Table 3.3.1, Table 3.3.2, Table 3.3.3 and Table 3.3.4 indicate the capelin specific model inputs.

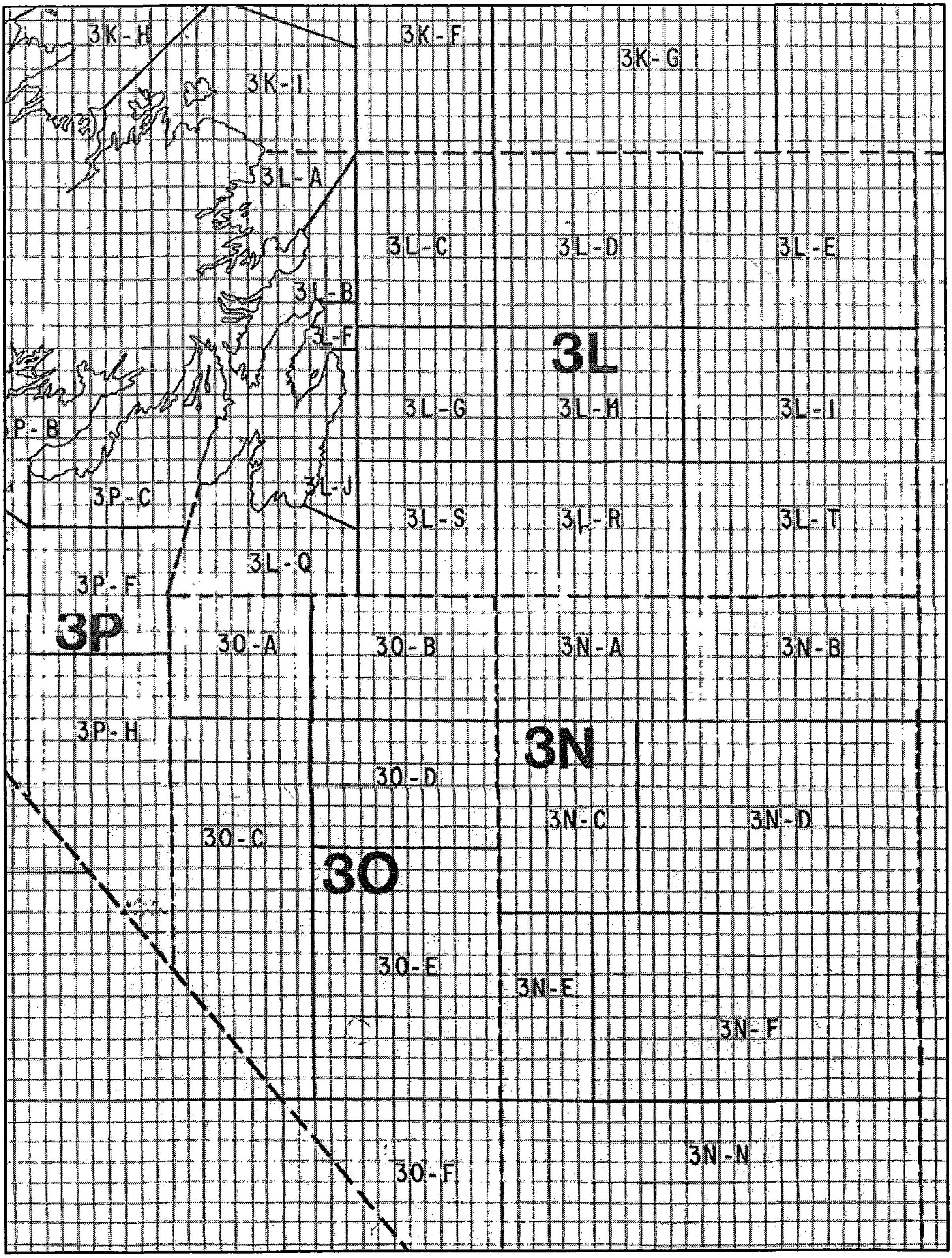

Figure 3.3.1 NAFO subdivisions (DFO)

- Vessels may operate in multiple areas in a given week in which case they are counted separately for each area.
- Table 3.3.2 gives the average weekly catch per vessel for each week and area combination, whereas Table 3.3.3 and Table 3.3.4 give the average weekly catch for all vessels and the number of vessels by week and by location, respectively. The average weekly catch per vessel can be derived from Table 3.3.2 by averaging (not summing) the values over the areas.

Table 3.3.1 Average Capelin Landed Price. Years 2000-2005 (Nominal $/kg)

Week	Price per Kg 3La	3Lb	3Lf
26	*	$0.20	$0.29
27	$0.25	$0.21	$0.29
28	$0.25	$0.21	$0.22
29	$0.18	$0.18	$0.18
30	$0.13	$0.13	$0.17
31	$0.13	$0.14	$0.14
32	$0.12	$0.24	*

Table 3.3.2 Average Weekly Catch per Vessel. Years 2000-2005 (kg/vessel)

Week	Average Catch (kg) per Vessel 3La	3Lb	3Lf
26	*	17,191	24,798
27	38,901	59,288	53,537
28	52,292	32,568	64,029
29	43,481	37,581	53,974
30	40,133	41,301	41,577
31	80,513	12,803	78,930
32	27,158	6,849	*

* No yield recorded,

- The average catch per vessel is the average of the weekly catches by area, not the sum of the weekly catches by location

Table 3.3.3 Average Weekly Catch and Number of Vessels. Years 2000-2005

Week	Catch	Number of Vessels
26	62,984	3
27	1,939,116	37
28	4,505,046	95
29	4,074,592	97
30	1,657,225	40
31	619,029	15
32	46,522	3

Table 3.3.4 Average Weekly Catch and Number of Vessels by Area. Years 2000-2005

Area	Catch	Number of Vessels
3La	3,408,555	72
3Lb	5,485,872	149
3Lf	4,010,086	70

3.4 Solution and Results

Solutions to the LP model for capelin are defined as particular configurations of the fishing fleet given by the number of vessels by gear type. The LP proceeds by searching the solution space of the feasible decision variable values to find the set that maximizes the objective function. This search is carried out using the Simplex algorithm (Winston 1994). The resulting objective function value, in our case the capelin revenue by weekly period and location of the capelin fishing fleet, can then be compared to historical data in order to validate the model.

The LP Simplex method is applied to the LP formulation using the Excel Add-In, *What'sBest! Professional* (LINDO 2009) to solve the model (as was mentioned in section 2.3.3). The current version of the software can solve LP models which have an upper bound on the number of constraints of 4,000 and on the number of decision variables of 8,000. The capelin problem is formulated with 21 decision variables (three areas by seven periods) and 20 constraints. The processing time for the capelin example was less than one second using the *What's Best Professional* software.

In Table 3.4.1 below the average annual landed value for capelin (annual data for 2000-2005) is compared with the objective function value from the capelin LP model described above. The model result represents a 4.9% increase over the historical value. This can be explained by the fact that the Simplex algorithm used in the model allocates vessels in a way that maximizes the objective function while satisfying the constraints. The model behaviour will be explained in more detail in the next section.

Results from the model are similar to historical data. The number of vessels by period only shows a difference with the historical data for period 31 with 9 vessels instead of 15, and the number of vessels by area show a slight difference (less than 10%) for area 3La with 65 instead of 72 (Figure 3.4.2).

Table 3.4.1 Comparison of Actual Historical Data vs Model Results

	Value
Historical Average	$2,541,380
Model Results	$2,665,087

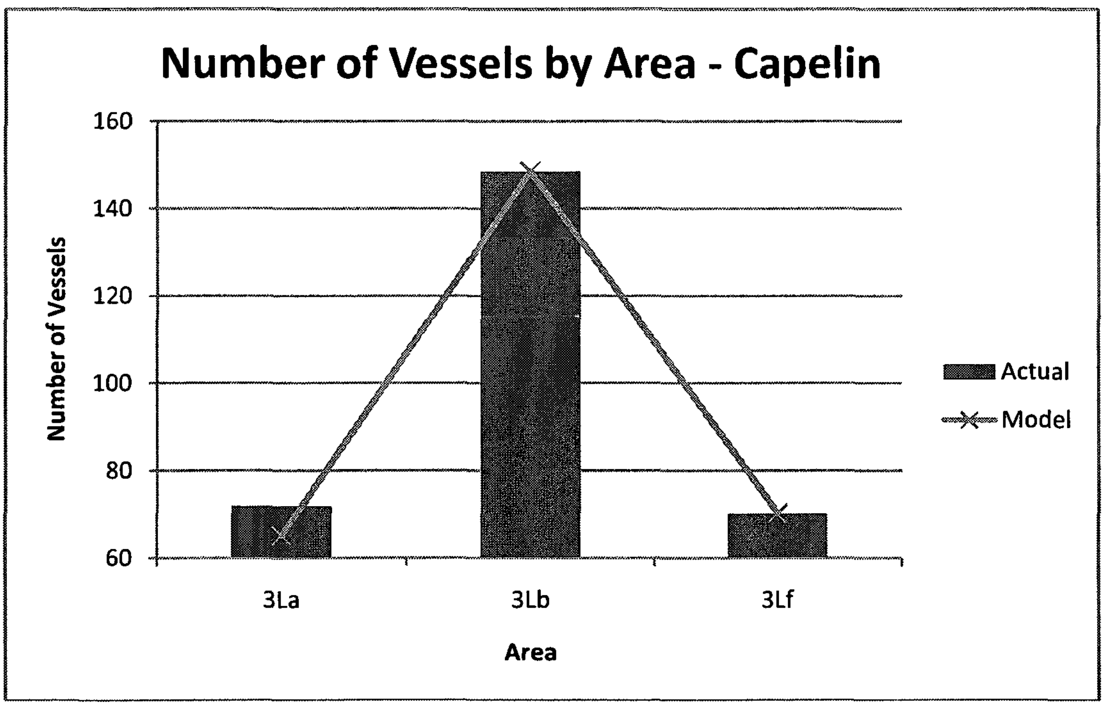

Figure 3.4.1 Comparison of Vessel Numbers by Area – Actual Data vs. Model

3.5 Model Behaviour

The Simplex algorithm used in the capelin LP model assigns vessels to each area and time period combination so as to maximize the landed value (revenue) defined by the objective function while respecting the limits on catch weight and fleet size imposed by the constraints. In the capelin example described above, there are three areas and seven periods, resulting in twenty-one decision variables. The relationship between the decision variables and the objective value is determined by the objective function coefficients, i.e., the change in the objective function value resulting from the change in a decision variable depends on the objective function coefficient. The feasible region, i.e. the set of vessel allocations that meet the constraints, is a convex set. (Winston 1994). When an optimal solution exists, i.e., a feasible solution that maximizes the objective function, there is an extreme point of the feasible region that is optimal. The Simplex algorithm moves through the extreme points of the feasible region until it reaches the point where no further improvement in the objective function can be gained by moving to another extreme point. Until this point has been reached, the choice of the next extreme point is based on the largest gain in the objective function value.

In our model, the number of vessels is constrained in two ways, by area and by time period. In other words there are constraints on the sum of the number of vessels over all time periods for each by area and on the sum of the number of vessels over all areas for each time period. These constraints are set according to historical average annual values for the years 2000 to 2005. The decision variables, i.e., the number of vessels, are defined for each feasible area and time period combination, but are constrained separately by area and time period. Therefore, when comparing model results with historical data by area or by time period, the number of vessels allocated by the model will be at most equal to corresponding historical values set as constraining limits. Also, since the model in this example maximizes landed value (not taking operating costs into account), the number of vessels allocated will tend toward constraint equalities as per the definition of extreme points.

When solving the LP, the Simplex algorithm moves through feasible solutions of vessel allocations by area and time period combination until an optimal solution is found. Since the algorithm selects new solutions that show the largest gain in objective function value while meeting the constraints, solutions will be chosen that allocate vessels to area and time period combinations with the highest objective function coefficients. Therefore the algorithm will assign higher values to those decision variables as described above, in a way that may not necessarily correspond to historical data as shown in Figure 3.5.1. However, aggregate results nevertheless correspond closely to actual data (see Figure 3.4.1 and Figure 3.5.1) indicating that vessel operators are inclined to act to maximize their landed value revenues where possible. This method of assigning decision variables values also explains the difference of 4.9% between the objective function value and the comparable historical value.

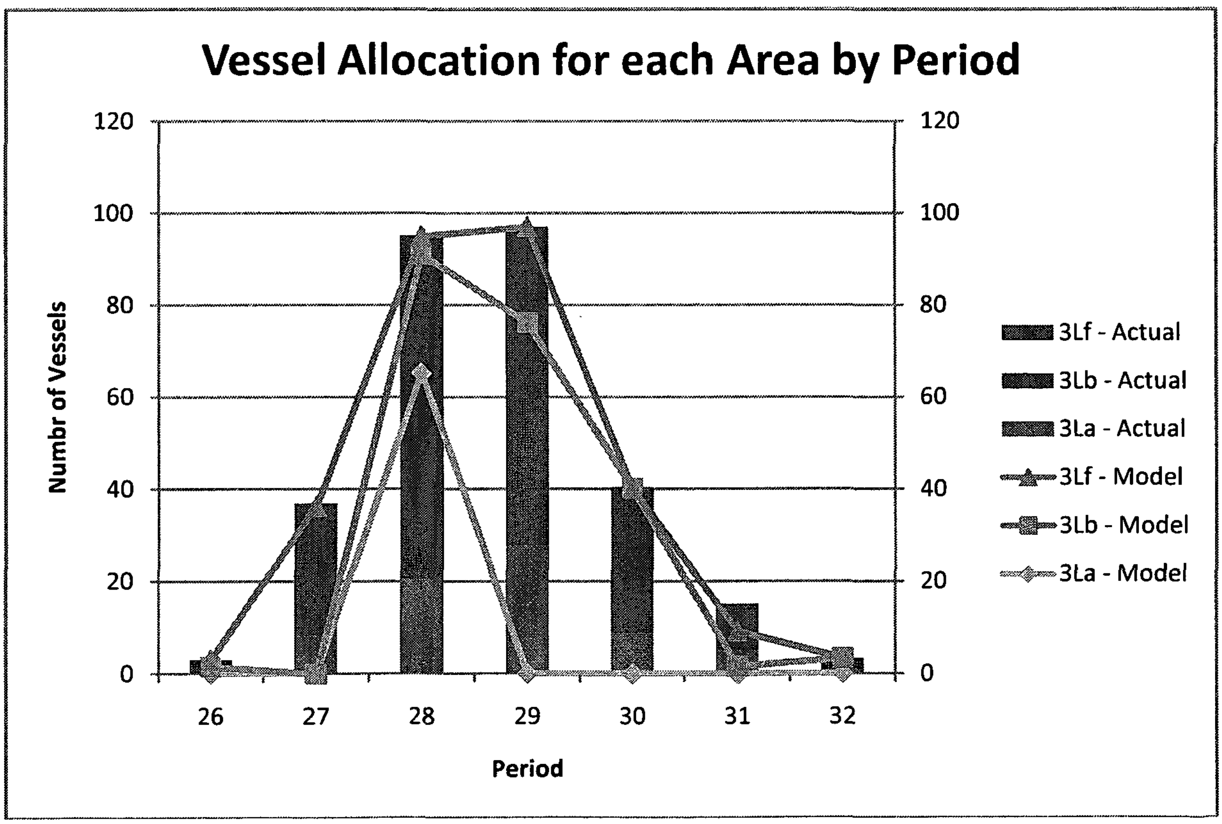

Figure 3.5.1 Comparison of Vessel Allocation – Actual Data vs. Model Results

The capelin LP model illustrates the application of the LP methodology to the Grand Banks fishing fleet. The next chapter examines the historical data for the Grand Banks fishing fleets and describes the separable fleet components for the system as a whole. As noted above, the LP model for capelin serves as an example for applying this methodology to the remaining fleet components described below.

The LP framework illustrated above for capelin is validated for the historical, average annual performance of the fleet. This result then allows the exploration of alternative formulations under varying conditions to anticipate future changes or to seek improved economic performance of the fleet sectors. The LP methodology permits a structured analysis of alternative formulations that are developed and carried out as model scenarios in Chapter 5 below.

4 Data and Analysis

In this chapter the extensive dataset for the Grand Banks fishery is analysed. The chapter presents the analytical approach the results of which are summarized. The full analysis of the data is presented in Appendix A of the thesis. The goal of the data analysis is twofold; first, we characterize the dynamics of the Grand Banks fishing fleet, and second, the results of the data analysis is used to drive the fishing fleet configuration liner programming model formulation and data needs as presented in Chapter 3.

The first part of this chapter details the source of the raw data on the Grand Banks fishery, and identifies the steps required to import the raw data into a spreadsheet in order to enable the analysis. The second part presents the data analysis, the results obtained and the justification for the use of these results to develop the fleet configuration model.

4.1 Data

The data used in the analysis are derived from historical data available from DFO's Zonal Interface Format Files (ZIFF) for the years 1995 to 2005. Each file contains all the records from reported individual commercial fishing vessel landings in NAFO Divisions 3L, 3N and 3O for one calendar year (Canada 2006a).

A single record contains the fields listed in Table 4.1.1. Each field is width-delimited and is either alphanumeric or floating point, indicated respectively by A and FP in the table's fourth column. The last column in the table specifies the field width and the position of the radix point in the case of a floating point field. The first number is the field width and the number after the decimal point is the position of the radix point. When that second digit is zero, the radix point is assumed to be integer. For example 5.2 represents a field width of five with the radix point in the third position from the right. The raw data from each ZIFF is imported into a spreadsheet document to perform the manipulation and analysis of the data.

Table 4.1.1 ZIFF Fields

Item	Name	Description	Value format	Field Width and Radix Point
1	cfva	Commercial Fishing Vessel Number	A	7
2	grosston	Gross Tonnage	FP	5.0
3	tclass	Gross Tonnage Class	FP	1.0
4	loa	Length Overall (in Feet)	FP	3.0
5	lclass	Length Class	FP	1.0
6	brakehp	Brake Horsepower	FP	5.0
7	bclass	Brake Horsepower Class	FP	1.0
8	tripno	Trip Number	FP	4.0
9	dateland	Date of Landing	FP	8.0
10	unitarea	NAFO Unit Area (See Figure 3.3.1)	A	5
11	gearcode	Gear Code	FP	2.0
12	gclass	Gear Class	FP	1.0
13	species	Species	FP	3.0
14	value	Landed Value	FP	10.2
15	weight	Landed Weight	FP	10.0
16	efflag	Effort Flag	A	1
17	daysfish	Days Fished	FP	5.2
18	hoursfish	Hours Fished	FP	5.1
19	amtgear	Amount of Gear	FP	4.0
20	ctchdate	Catch Date	FP	8.0
21	lat	Latitude	FP	12.8
22	long	Longitude	FP	12.8
23	region	Region	A	1
24	year	Year	FP	4.0
25	month	Month	FP	2.0

4.2 Raw Data Manipulation

Each line of text in every ZIFF corresponds to one record. By specifying the field width of each record, as per the format table (above) it is possible to import the data into a spreadsheet. Each row of the spreadsheet corresponds to a record and each column corresponds to a particular field in that record. Due to the large number of records for certain years, it is necessary to split the raw data into two separate files, otherwise they do not fit in their entirety on a single Microsoft Excel spreadsheet. Table 4.2.1 below indicates the total number of records per year, i.e. in each ZIFF in this analysis. Files totalling more than 65,536 records (the Excel row size import limit) are split and imported in two separate Excel spreadsheets. Despite the data management issues, the large volume of available data records contained in the ZIFFs makes these records suitable for creating a representative model of the Grand Banks fishing fleet configuration. Table 4.2.1 presents the annual records of the Grand Banks fishing fleet for 1995 to 2005.

Table 4.2.1 Number of records per year

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Number of Records	49667	69284	70750	65501	62535	72586	81125	93187	90837	79363	91709

The goal of the data analysis is to examine the detailed dynamics of the commercial fisheries on the Grand Banks.

4.3 Analysis and Results

The large number of records available for each year also necessitates the filtering out of data by retaining only what is significant for the purpose of this study. This is achieved by selecting the main species that are prosecuted in the area of study, and the primary gear types used for their capture. The procedures used to select these elements from the full ZIFF dataset are described below.

4.3.1 Species Selection

The first step in this process is to rank the species. The indicator used for the comparison is the cumulative total landed value which is computed for each species for the years 1995 to 2005. Table 4.3.1 below shows the ranking of the top twenty species in the ZIFF dataset by cumulative landed value over the data period.

Table 4.3.1 Species Ranking by Cumulative Total Landed Value. Years 1995-2005

Species	Cumulative Value	Percentage	Rank
Snow Crab	$1,082,536,338	68.55%	1
Northern Shrimp	$73,657,139	4.66%	2
Stimpsons Surf Clams	$68,249,708	4.32%	3
Yellowtail Flounder	$62,113,599	3.93%	4
Icelandic Scallops	$33,981,822	2.15%	5
Cod	$32,573,998	2.06%	6
Capelin	$26,403,795	1.67%	7
Redfish	$21,394,395	1.35%	8
Greenland Halibut	$21,050,573	1.33%	9
Swordfish	$18,973,705	1.20%	10
Lobster	$15,910,997	1.01%	11
Cockles	$13,318,721	0.84%	12
Atlantic Halibut	$12,716,980	0.81%	13
Lumpfish Roe	$11,493,994	0.73%	14
Monkfish	$10,322,868	0.65%	15
Beater Harp Seal Skins	$9,210,320	0.58%	16
Sea Urchins	$7,662,067	0.49%	17
American Plaice	$6,727,396	0.43%	18
Bluefin Tuna	$5,960,700	0.38%	19
Stimpsons clams, Mantel and Body Meat	$4,864,942	0.31%	20
Total	$1,504,698,631	95.29%	

4.3.1.1 Species Ranking by Landed Value

Snow crab is a highly valuable species for the Grand Banks commercial fishery, accounting for more than two-thirds of the cumulative total landed value for the years 1995 to 2005 for all species. Snow Crab landings for that period are worth more than one billion dollars. Landed values for Northern shrimp and surf clams account for over 4% of cumulative value. Yellowtail flounder, scallops, and cod (the historically dominant species on the Grand Banks) have value yields in excess of 2% overall. All other species record cumulative values of under 2%, Monkfish catches rank 15th over all species with a cumulative valuation of under 1%. We can conclude that the top fifteen species represent a significant proportion of the landed value of all species. The number of species selected for our study is reduced to fifteen as listed in Table 4.3.2 below. American Plaice is a historically significant and highly sought after species that has been under moratorium since 1995. Nonetheless, its total landed value puts it in 18th position by cumulative total landed value. It is therefore included in the list of selected species.

Table 4.3.2 Selected Species

Selected Species	Species Category
Cod	
Redfish	
Atlantic Halibut	
American Plaice	**Groundfish**
Yellowtail Flounder	
Greenland Halibut	
Monkfish	
Lumpfish Roe	
Swordfish	**Large Pelagic**
Capelin	**Small Pelagic**
Stimpons Surf Clams	
Cockles	
Icelandic Scallops	**Invertebrates**
Lobster	
Northern Shrimp	
Snow Crab	

4.3.1.2 Cockles and Icelandic Scallops

Table 4.3.3 below shows that data on landed values for Cockles and Icelandic Scallops are problematic. There is a precipitous decline in the landed value of Cockles from a high of $14,675,655 in 1996 to a low of $0 in 2001 to 2004. However, the landed value of Icelandic Scallops is nil from 1996 to 2002 and increases suddenly to landings worth millions of dollars in 2003 to 2005. Because the data show that the same gear type harvests both species in the same locations, then the decision is to amalgamate these two species (cockles and Icelandic scallops) and treat them as one species for the purpose of our data analysis.

Table 4.3.3 Comparison of Icelandic Scallops and Cockles Annual Landed Values

Year	Cockles	Icelandic Scallops
1995	$30,242	$9,768,187
1996	$0	$14,764,655
1997	$0	$6,384,624
1998	$0	$2,073,502
1999	$0	$210,109
2000	$0	$490,666
2001	$0	$0
2002	$0	$0
2003	$4,006,268	$0
2004	$3,722,574	$0
2005	$5,559,638	$234,316

4.3.1.3 Updated Species Selection

The final list of selected species in Table 4.3.4 reflects the amalgamation of Cockles and Scallops. The species selection captures 95.71% of the total landed value (see Table 4.3.6 below).

Table 4.3.4 Updated Species Selection

	Selected Species	Species Category
1	Cod	
2	Redfish	
3	Atlantic Halibut	
4	American Plaice	**Groundfish**
5	Yellowtail Flounder	
6	Greenland Halibut	
7	Monkfish	
8	Lumpfish Roe	
9	Swordfish	**Large Pelagic**
10	Capelin	**Small Pelagic**
11	Stimpons Surf Clams	
12	Cockles and Icelandic Scallops	
13	Lobster	**Invertebrates**
14	Northern Shrimp	
15	Snow Crab	

4.3.1.4 Naming Conventions

The following naming conventions will be used henceforth:

Simpsons Surf Clams will be referred to as Clams, Icelandic Scallops as Scallops and Lumpfish Roe as Lumpfish.

4.3.2 Gear Type Selection

A second consolidation in the number of ZIFF records can be achieved by keeping only the main gear types that are used to prosecute the species identified above. The following gear types covering the 15 species are selected as noted in Table 4.3.5:

Table 4.3.5 Selected Gear Types.

Selected Gear Types
Midwater Trawl
Shrimp Trawl
Beach and Bar Seine
Purse Seine
Gillnet
Longline
Hand Line
Trap Net
Pot
Dredge
Otter Bottom Trawl

Table 4.3.6 below shows the impact of selecting the records containing the gear types listed above. The result is a decrease of only 0.05% relative to the cumulative total landed value for all records from 1995 to 2005, after the species selection has been made. In other words, the species selection captures 95.71% of the total landed value, and the subsequent gear selection reduces the total landed value of remaining records to 95.66%. It is therefore concluded that the selected gear types and species are significant and representative of the entire value for the Grand Banks fleet for the purpose of our study.

Table 4.3.6 Impact of Gear Selection on Landed Value

Cumulative Total Landed Value 1995-2005				
Species	All Gears	Percentage	Selected Gears	Percentage
Snow Crab	$1,082,536,338	68.55%	$1,082,536,338	68.55%
Northern Shrimp	$73,657,139	4.66%	$73,645,474	4.66%
Clams	$68,249,708	4.32%	$68,249,708	4.32%
Yellowtail Flounder	$62,113,599	3.93%	$61,720,142	3.91%
Cockles and Scallops	$47,300,544	3.00%	$45,227,042	3.00%
Cod	$32,573,998	2.06%	$32,560,837	2.06%
Capelin	$26,403,795	1.67%	$26,174,554	1.66%
Redfish	$21,394,395	1.35%	$21,394,395	1.35%
Greenland Halibut	$21,050,573	1.33%	$21,050,570	1.33%
Swordfish	$18,973,705	1.20%	$17,728,002	1.20%
Lobster	$15,910,997	1.01%	$14,529,599	1.01%
Atlantic Halibut	$12,716,980	0.81%	$11,689,721	0.81%
Lumpfish Roe	$11,493,994	0.73%	$11,260,277	0.73%
Monkfish	$10,322,868	0.65%	$9,986,399	0.65%
American Plaice	$6,727,396	0.43%	$6,602,187	0.42%
Total	**$1,511,426,028**	**95.71%**	**$1,510,652,947**	**95.66%**

4.3.3 Data Filtering Summary

The selection of species and gear listed above significantly reduces the overall number of records. Table 4.3.7 below gives a summary of the filtered data, comparing the original number of records to the final number of records and the value of landings for the filtered data to the total value of landings for each year from 1995 to 2005. The total number of records is reduced by 268,463 from 826,521 to 558,058. The selection of a subset of species and gear types from the original dataset greatly reduces the number of records without significant loss in value, and facilitates the data analysis, which is performed in the next section.

Table 4.3.7 Summary of Filtered Data

Year	1995	1996	1997	1998	1999	2000
Total Number of Records	49667	69284	70750	65501	62535	72565
Remaining number of records	30500	48732	36916	45812	49325	53828
Number of records removed	19167	20552	33834	19689	13210	18737
Total Value	$110,910,332	$83,382,342	$76,664,377	$75,374,234	$139,866,460	$168,950,015
Remaining Value	$105,765,341	$77,070,990	$66,161,685	$71,279,519	$135,683,477	$164,421,030
Percentage of total value	**95.36%**	**92.43%**	**86.30%**	**94.57%**	**97.01%**	**97.32%**

Table 4.3.7 **Continued**

Year	2001	2002	2003	2004	2005	Total
Total Number of Records	81125	93187	90837	79361	91709	826521
Remaining number of records	62093	61886	56445	52868	59653	558058
Number of records removed	19032	31301	34392	26493	32056	268463
Total Value	$160,808,907	$165,971,102	$213,779,833	$223,665,163	$159,751,418	$1,579,124,183
Remaining Value	$156,238,588	$155,938,565	$205,029,402	$219,828,999	$153,235,351	$1,510,644,595
Percentage of total value	**97.16%**	**93.96%**	**95.91%**	**98.28%**	**95.92%**	**95.66%**

4.3.4 Data Analysis

Now that the significant species and gear have been selected, we turn our attention to the analysis of the Grand Banks commercial fishery, with the aim to obtain a complete characterization of its dynamics. The first query concerns the variability of landings, i.e. whether they are comparable from one year to the next or vary significantly. Table 4.3.8 and Table 4.3.9 show the annual landed value by species for the years 1995 to 2005, and Table 4.3.10 presents the corresponding percentages.

Total landed values vary dramatically from year to year, from a low of $66,165,278 in 1997 to a high of $219,829,356 in 2004. This trend can be explained in part by changes in landed value of Snow Crab, since it represents such a large portion of the total. However, each species shows large fluctuations in annual landed value from year to year, with the exception of Lobster, which exhibits a steadier, albeit decreasing, pattern. Yellowtail Flounder and Shrimp show large increases in their respective landed values, starting at negligible amounts to over $10.5 million for the former and close to $17 million for the latter. On the other hand, Cockles and Scallops' landed values decline precipitously from a high of nearly $15 million in 1996 to a low of $0 in 2002, rebounding to close to $6 million in 2005. We conclude that landed values can show very large fluctuations from year to year. They are therefore difficult to predict: hence the importance of performing scenario analysis with a wide array of potential future landed values using our model. The analysis continues with the spatial dimension of the landings.

Table 4.3.8 Annual Total Landed Values - Selected Species – 1995-2000

Species	Landed Value					
	1995	1996	1997	1998	1999	2000
Cod	$308,802	$363,082	$709,751	$3,909,142	$7,343,855	$5,184,062
Redfish	$56,753	$2,032,233	$1,221,263	$4,920,360	$1,378,108	$877,914
Atlantic Halibut	$591,887	$691,780	$1,254,578	$1,027,125	$813,762	$1,172,981
American Plaice	$59,068	$49,202	$57,839	$189,091	$261,814	$499,698
Yellowtail Flounder	$2,435	$82	$479	$3,025,893	$4,405,653	$7,673,445
Greenland Halibut	$604,614	$2,261,752	$1,139,242	$1,094,690	$928,184	$3,325,562
Lumpfish	$1,303,150	$1,477,793	$964,578	$233,717	$932,765	$755,857
Monkfish	$142,068	$226,223	$326,920	$336,469	$167,002	$154,160
Swordfish	$1,031,307	$1,709,711	$1,611,095	$1,245,703	$2,380,604	$1,145,527
Capelin	$37,017	$2,904,300	$1,508,391	$4,478,694	$1,830,935	$2,037,026
Clams	$15,124,321	$6,016,342	$6,029,082	$769,366	$1,164,688	$2,901,499
Cockles and Scallops	$9,798,429	$14,764,655	$6,384,624	$2,073,502	$210,109	$490,666
Lobster	$1,824,720	$1,635,762	$1,465,839	$1,381,397	$1,629,426	$1,440,791
Northern Shrimp	$0	$8,541	$0	$17,846	$344,442	$7,382,674
Snow Crab	$74,881,660	$42,929,531	$43,488,005	$46,607,851	$111,894,502	$129,417,394
Total	**$105,766,232**	**$77,072,555**	**$66,165,278**	**$71,311,043**	**$135,685,849**	**$164,459,630**

Table 4.3.9 Annual Total Landed Values - Selected Species – 2001-2005

Species	Landed Value				
	2001	2002	2003	2004	2005
Cod	$5,616,735	$4,389,040	$2,335,188	$1,147,831	$1,266,510
Redfish	$3,173,501	$1,884,061	$1,796,628	$1,199,643	$2,853,930
Atlantic Halibut	$1,671,699	$1,301,864	$1,891,308	$907,130	$1,392,866
American Plaice	$1,289,931	$1,108,797	$1,228,517	$1,017,992	$965,446
Yellowtail Flounder	$9,889,917	$8,031,783	$9,130,179	$9,482,720	$10,471,013
Greenland Halibut	$2,880,193	$1,637,229	$2,318,944	$1,819,749	$3,040,414
Lumpfish	$949,301	$355,837	$559,846	$2,912,175	$1,048,976
Monkfish	$860,510	$2,792,311	$3,551,699	$772,964	$992,542
Swordfish	$1,427,130	$943,853	$2,355,023	$2,300,324	$2,823,429
Capelin	$2,004,578	$1,110,356	$2,085,434	$3,998,400	$4,408,663
Clams	$6,849,822	$5,328,774	$12,380,278	$7,457,845	$4,227,691
Cockles and Scallops	$55,763	$0	$4,006,268	$3,722,574	$5,793,954
Lobster	$1,499,628	$1,507,314	$1,338,763	$837,407	$1,349,949
Northern Shrimp	$9,635,235	$9,825,486	$16,756,074	$13,669,564	$16,017,277
Snow Crab	$108,701,168	$115,925,358	$143,295,252	$168,583,037	$96,812,580
Total	**$156,505,111**	**$156,142,062**	**$205,029,402**	**$219,829,356**	**$153,465,239**

Table 4.3.10 Percentage of Total Annual Landed Values - Selected Species

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Species						Percentage					
Cod	0.28%	0.44%	0.93%	5.19%	5.25%	3.07%	3.49%	2.64%	1.09%	0.51%	0.79%
Redfish	0.05%	2.44%	1.59%	6.53%	0.99%	0.52%	1.97%	1.14%	0.84%	0.54%	1.79%
Atlantic Halibut	0.53%	0.83%	1.64%	1.36%	0.58%	0.69%	1.04%	0.78%	0.88%	0.41%	0.87%
American Plaice	0.05%	0.06%	0.08%	0.25%	0.19%	0.30%	0.80%	0.67%	0.57%	0.46%	0.60%
Yellowtail Flounder	0.00%	0.00%	0.00%	4.01%	3.15%	4.54%	6.15%	4.84%	4.27%	4.24%	6.55%
Greenland Halibut	0.55%	2.71%	1.49%	1.45%	0.66%	1.97%	1.79%	0.99%	1.08%	0.81%	1.90%
Lumpfish Roe	1.17%	1.77%	1.26%	0.31%	0.67%	0.45%	0.59%	0.21%	0.26%	1.30%	0.66%
Monkfish	0.13%	0.27%	0.43%	0.45%	0.12%	0.09%	0.54%	1.68%	1.66%	0.35%	0.62%
Swordfish	0.93%	2.05%	2.10%	1.65%	1.70%	0.68%	0.89%	0.57%	1.10%	1.03%	1.77%
Capelin	0.03%	3.48%	1.97%	5.94%	1.31%	1.21%	1.25%	0.67%	0.98%	1.79%	2.76%
Clams	13.64%	7.22%	7.86%	1.02%	0.83%	1.72%	4.26%	3.21%	5.79%	3.33%	2.65%
Cockles and Scallops	8.84%	17.71%	8.33%	2.75%	0.15%	0.29%	0.03%	0.00%	1.87%	1.66%	3.63%
Lobster	1.65%	1.96%	1.91%	1.83%	1.16%	0.85%	0.93%	0.91%	0.63%	0.37%	0.85%
Northern Shrimp	0.00%	0.01%	0.00%	0.02%	0.25%	4.37%	5.99%	5.92%	7.84%	6.11%	10.03%
Snow Crab	67.52%	51.49%	56.73%	61.84%	80.00%	76.60%	67.60%	69.85%	67.03%	75.37%	60.60%
Total	**95.36%**	**92.43%**	**86.31%**	**94.61%**	**97.01%**	**97.34%**	**97.32%**	**94.08%**	**95.91%**	**98.29%**	**96.07%**

4.3.5 Spatial Analysis

Each record in a ZIFF contains information about the precise location of the recorded catch. This information is used to examine the spatial distribution of the catch between NAFO divisions 3L, 3N and 3O (see Figure 3.3.1). All related data tables and graphs may be found in Appendix A – Data and Analysis of the thesis. Spatial examples for NAFO division 3L are presented in Figure 4.3.1 (landed value) and Figure 4.3.2 (landed weight).

Spatial data analysis results in several observations as noted below:

- Cod, Lobster, Northern Shrimp, Capelin and Snow Crab are primarily captured in NAFO division 3O.
- Greenland Halibut is also mainly captured in 3L with 3O accounting for a maximum of 37% of total catch.
- Redfish and Monkfish are captured in significant amounts in area 3O.
- Atlantic Halibut originates mainly from 3O with the exception of the year 2001 that sees an increase in 3L's share of the catch and a decrease of 3N's share in 2002.
- American Plaice sees a large increase in catch in 2001 with the majority of the catch occurring in 3N.
- Swordfish harvests take place mainly in area 3O with 3N accounting for a maximum of 49% of total catch in 1999.
- Scallop catches originate mainly from area 3N with 3L accounting for a maximum of 17% of total catches in 2001.

The distribution of the landed weights according to their area of origin shows a clear localization of the origin of the catch. This warrants a further analysis of the spatial distribution of the catch by the subdivision of areas 3L, 3N and 3O, a task that is performed in section 4.6 below. The examples in Figures 4.3.1 and 4.3.2 also show a clear pattern of high variability in landed value and landed weight from year to year and are representative of all species in this regard. A notable exception is Lobster, which shows an overall decline in yearly landed value and landed weight. In addition, the average annual real landed price per kg (in 2005 dollars) shows variations depending on the area of origin of the catch (Tables

4.3.11 through 4.3.13). The analysis of the landed value, the landed weight and the resulting landed price of the catch by area clearly shows the importance of taking into account the area of origin when formulating the LP model as each of these components vary significantly by location. Next, we examine the seasonality of the catch before performing a more detailed spatial analysis of the catch.

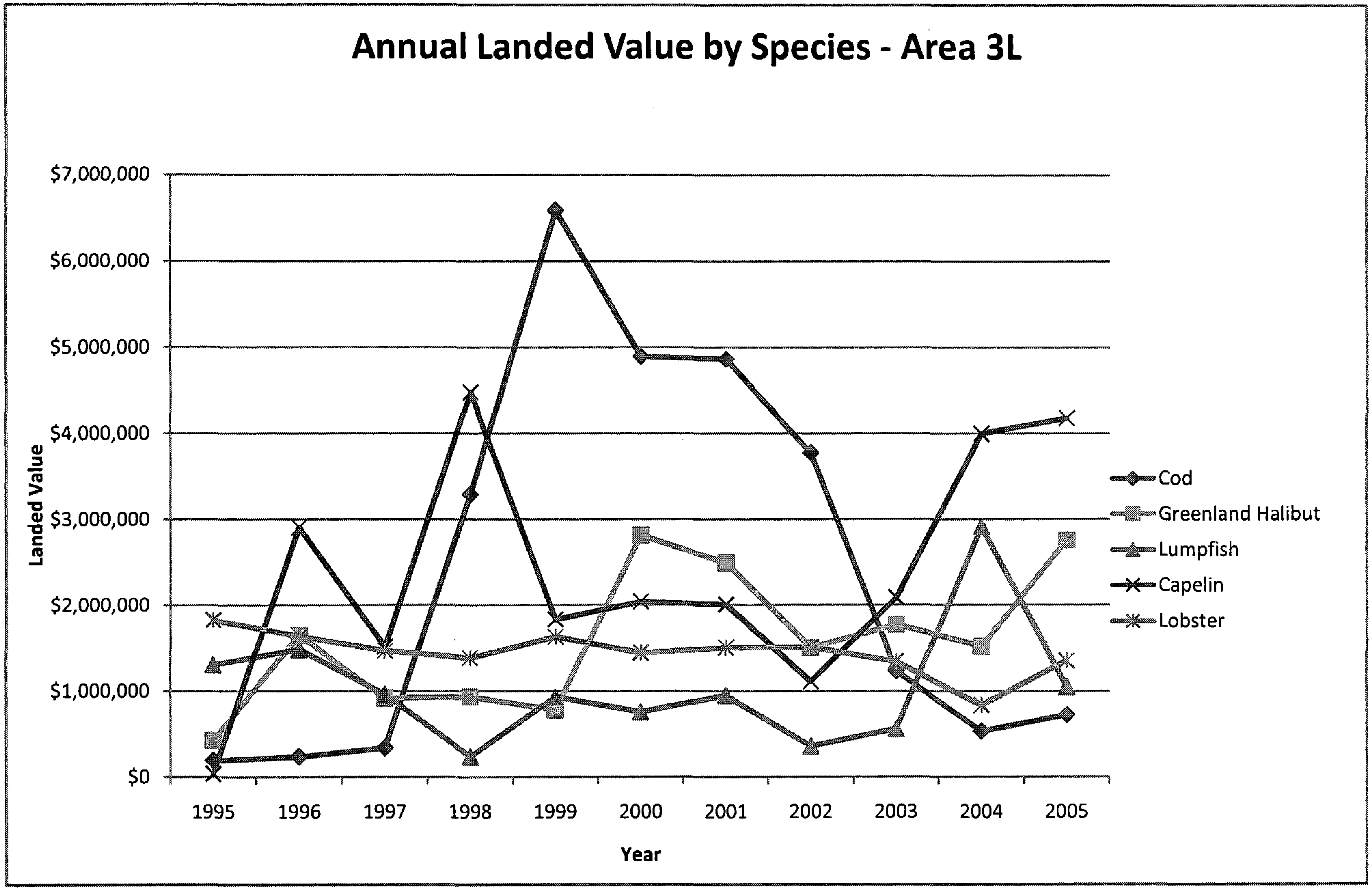

Figure 4.3.1 Annual Landed Value by Species - Area 3L. Cod, Greenland Halibut, Lumpfish, Capelin and Lobster. Years 1995-2005

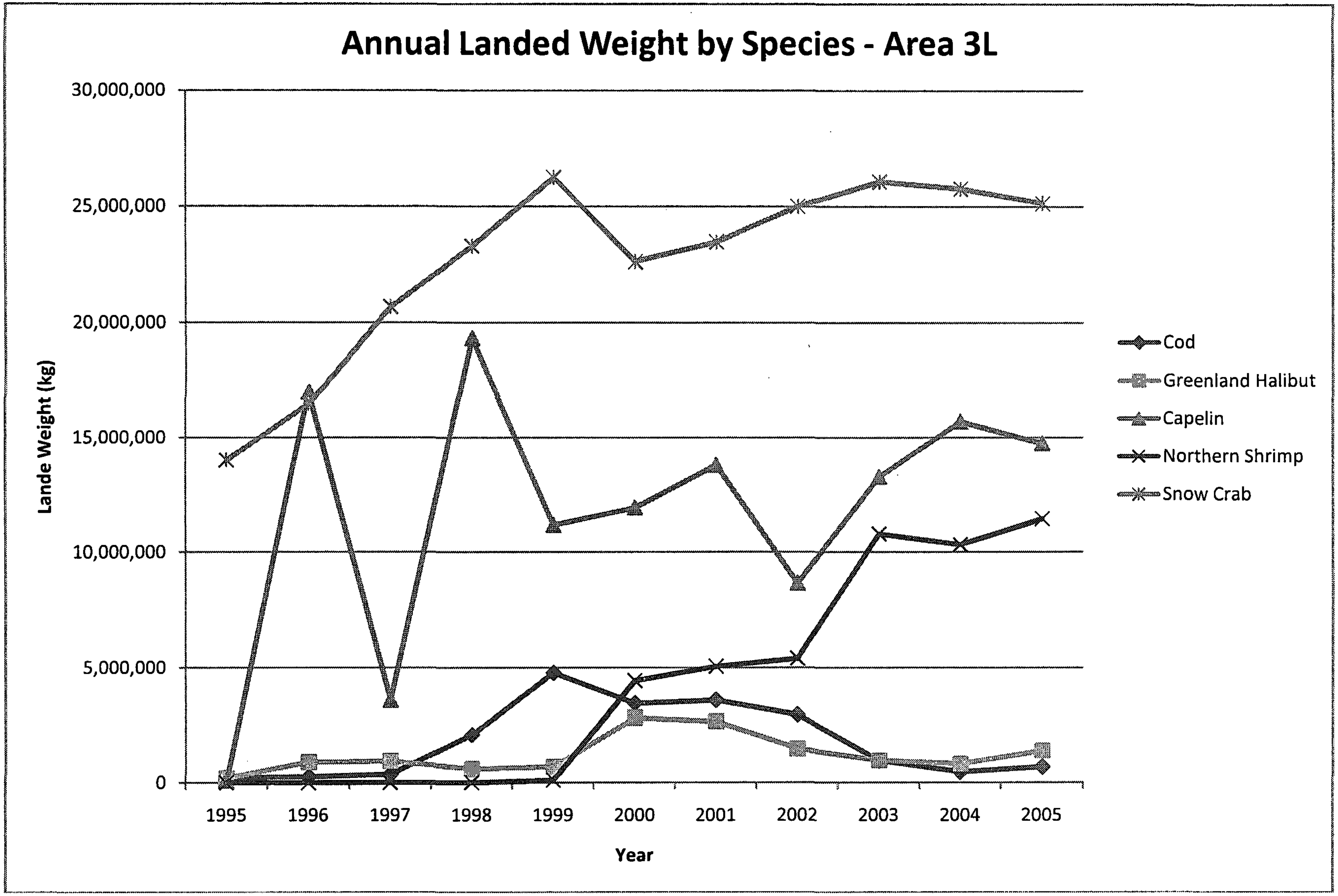

Figure 4.3.2 Annual Landed Weight by Species – Area 3L. Cod, Greenland Halibut, Capelin, Northern Shrimp and Snow Crab. – 1995-2005.

Table 4.3.11 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3L. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.10	$1.13	$1.10	$1.85	$1.59	$1.59	$1.47	$1.36	$1.35	$1.18	$1.07
Redfish	$0.34	$2.86	$1.72	$0.76	$0.64	$0.64	$0.72	$0.68	$0.59	$0.54	$0.53
Atlantic Halibut	$6.28	$7.11	$6.46	$6.53	$5.81	$5.92	$7.54	$6.16	$6.89	$6.65	$6.55
American Plaice	$1.06	$1.29	$1.40	$0.95	$0.94	$0.90	$0.83	$0.86	$0.80	$0.78	$0.66
Greenland Halibut	$2.64	$2.22	$1.16	$1.85	$1.32	$1.11	$1.01	$1.09	$1.92	$1.90	$2.00
Lumpfish	$8.05	$7.94	$5.24	$2.58	$2.79	$2.47	$5.02	$6.77	$6.00	$5.49	$3.12
Monkfish	$1.39	$2.20	$1.53					$1.79	$1.72		
Swordfish	$10.43	$8.67	$8.01								
Capelin	$0.42	$0.21	$0.49	$0.27	$0.19	$0.19	$0.16	$0.14	$0.16	$0.26	$0.28
Clams		$1.11				$1.00	$0.87			$1.38	
Cockles and Icelandic Scallops	$1.76	$1.76	$1.89	$1.86	$1.72	$1.65	$1.59			$1.07	$1.55
Lobster	$11.97	$11.19	$12.51	$11.06	$11.84	$12.84	$13.11	$12.63	$12.04	$11.67	$12.17
Northern Shrimp				$1.57	$3.56	$1.86	$2.07	$1.95	$1.62	$1.35	$1.40
Snow Crab	$6.51	$3.05	$2.32	$2.27	$3.93	$5.40	$4.18	$4.13	$4.71	$5.51	$3.19

Table 4.3.12 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3N. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.80	$1.73	$1.33	$1.85	$1.61	$1.53	$1.50	$1.48	$1.37	$1.31	$1.15
Redfish			$0.91	$0.70	$0.69		$0.72				$0.52
Atlantic Halibut	$9.32	$6.44	$8.25	$8.49	$9.28	$8.39	$8.27	$6.15	$8.58	$8.47	$8.81
American Plaice	$0.94	$0.99	$0.88	$0.94	$0.93	$0.90	$0.87	$0.86	$0.80	$0.80	$0.66
Greenland Halibut			$1.30	$1.80		$1.10	$0.90	$1.15	$1.78	$1.84	$1.92
Lumpfish											
Monkfish	$2.46		$1.51			$1.83	$1.79	$1.79	$1.77		$1.67
Swordfish		$10.32	$7.57	$6.88	$6.64	$7.04	$6.83	$7.45		$7.69	$8.28
Capelin											
Clams	$1.37	$1.12	$0.96	$0.94	$0.90	$1.00	$0.88	$0.82	$1.27	$1.20	$1.06
Cockles and Scallops	$1.66	$1.80	$1.89	$1.86	$1.72	$1.63	$1.58		$1.29	$0.85	$0.85
Lobster											
Northern Shrimp						$1.43					$1.15
Snow Crab		$3.09	$2.32	$2.27	$3.93	$5.40	$4.18	$4.13	$4.74	$5.51	$3.19

Table 4.3.13 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3O. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.75	$1.51	$1.34	$1.79	$1.59	$1.54	$1.52	$1.46	$1.41	$1.29	$1.08
Redfish	$0.39	$0.34	$0.55	$0.65	$0.68	$0.44	$0.70	$0.66	$0.60	$0.47	$0.52
Atlantic Halibut	$8.62	$7.23	$7.17	$7.28	$6.65	$7.02	$6.64	$6.58	$7.40	$7.19	$7.42
American Plaice	$1.12	$1.05	$0.82	$0.92	$0.93	$0.90	$0.87	$0.86	$0.80	$0.80	$0.66
Greenland Halibut	$1.87	$2.19	$1.41	$1.81	$1.32	$0.94	$1.18	$1.31	$2.22	$2.14	$2.36
Lumpfish											
Monkfish	$1.79	$1.79	$1.12	$1.74	$1.74	$1.85	$1.78	$1.77	$1.68	$1.09	$1.60
Swordfish	$10.63	$10.57	$9.23	$7.62	$8.26	$7.99	$7.64	$8.64	$9.64	$8.50	$8.32
Capelin											
Clams		$1.01							$0.85		
Cockles and Scallops	$1.63		$1.93	$1.86							$2.10
Lobster											
Northern Shrimp		$2.38									
Snow Crab	$6.72	$3.12	$2.30	$2.27	$3.93	$5.40	$4.18	$4.13	$4.75	$5.48	$3.13

4.3.6 Time Analysis

In order to characterize the seasonal dynamics of the commercial fisheries on the Grand Banks, it is necessary to perform an in-season time period (weekly) analysis. The complete set of graphs showing the weekly landings by gear type for the years 1995 to 2005, according to the in-season weekly catch dates are found in Appendix A – Data Analysis.

The first observation that can be made regarding weekly catches is the high level of seasonality. In other words, there is a clear pattern of high catches by species during the same time periods year after year. Similarly, catches that are relatively low at the beginning of each fishing season increase gradually to a peak that lasts from a few weeks to several months and decline until the end of the season. There are occasional spikes outside of the main fishing season as in the case of Shrimp Trawlers. Most gear types show one season of high catches, with the exception of Bottom Otter Trawlers that shows two such seasons (see Figure 4.3.3 below).

The duration of the fishing season can be very short for some gear types as is the case with Purse Seine, Beach and Bar Seine and Trap Nets who operate at most one month out of the year during exactly the same time from year to year. Other gear types, such as Dredges, operate throughout the year. There is no visible pattern in Midwater Trawl catches, an issue which will be addressed in section 4.4 below. We can conclude that patterns of weekly catches are comparable from year to year and show clear seasonality in the activity of fishing vessels. Figure 4.3.3 below is an example of weekly landed weight for the years 1995 to 2005. In this and in the previous sections we established the seasonality and the spatial dimension of the catch, respectively. In order to further characterize the dynamics of the Grand Banks fishing fleet we establish, in the next section, which combinations of species and gear types are significant. The spatial and time components of the analysis can then be further refined by taking into account these combinations.

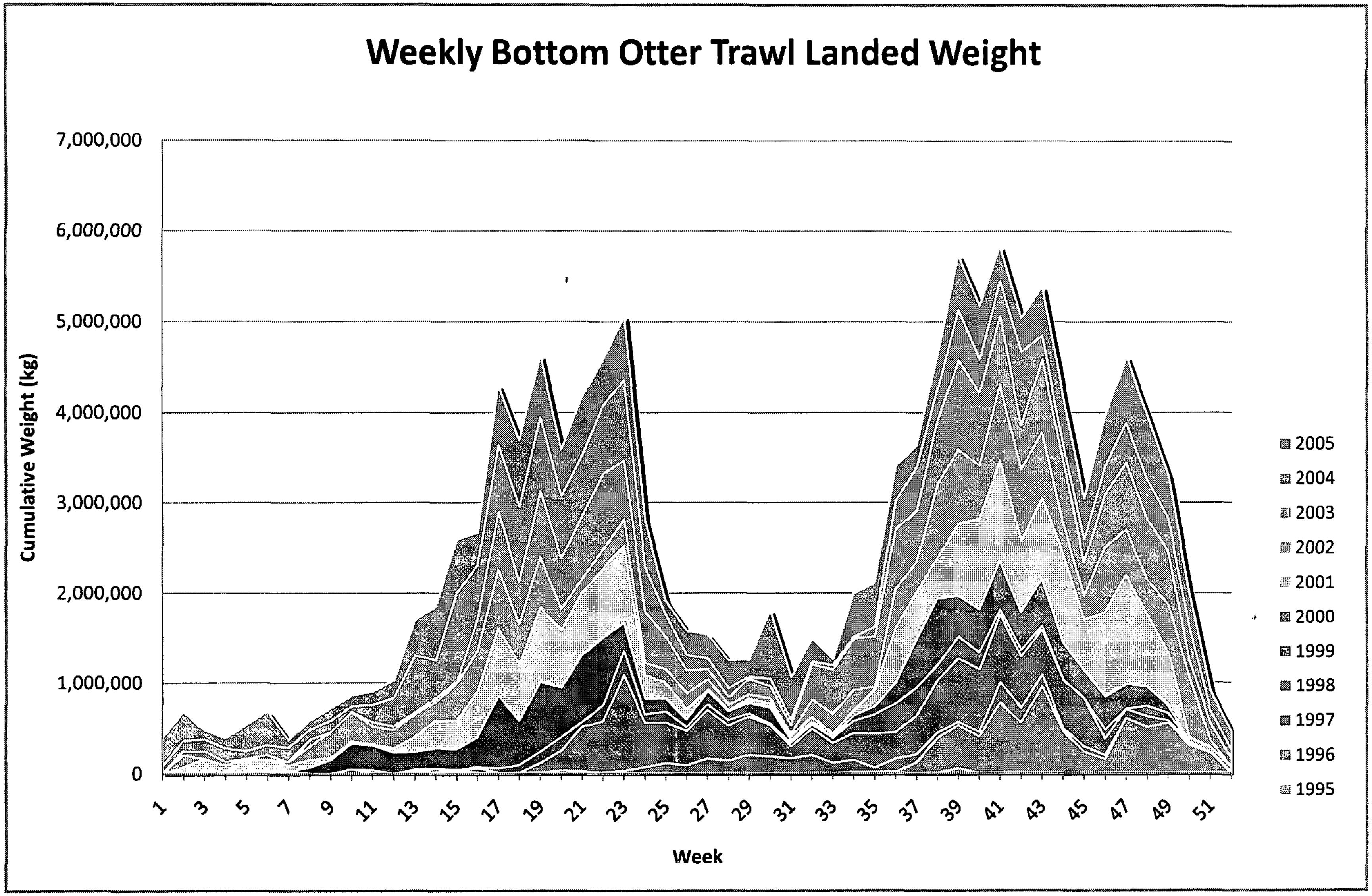

Figure 4.3.3 Weekly Bottom Otter Trawl Landed Weight - Years 1995-2005

4.3.7 Gear Type and Species Combinations

Further characterization of the Grand Banks fishing fleet requires the identification of all significant combinations between species and gear types. This is accomplished by examining the average annual catch by gear type for each species and the average annual catch by species for each gear type. An example of the first is the identification of the main gear types that harvest Yellowtail Flounder, and an example of the second is the identification of the main species that are captured by Gillnets. Although there is a large overlap in the information that these analyses provide, the combined data create important indicators that are instrumental in the selection of significant gear/ species combinations. When a species represents a very small portion of a gear type's landings we can choose not to select that gear and species combination if no other information is available. For example, Trap Net represents 2% of average annual Cod catches but only 1% of its catch is Cod, so we do not include Cod as a significant species for Trap Net. Conversely, if a single gear type is the sole method of harvest for a species - a fact which is quickly revealed by the combined gear-species analysis - then it is necessary to select that gear type and species combination. For example, Lobster only represents 1% of all Pot gear landings, but that is the unique gear type that harvests Lobster and it therefore identified as a key combination.

4.3.7.1 Average Annual Catch by Gear Type for each Species

In this section we examine the relationship between gear type and species, i.e., which species are prosecuted by each gear type and in what proportion. Table 4.3.14 below shows which gear types harvest each species. An example of the percentage of total cod catches and the corresponding weight captured by each gear type that catches cod is shown in Figure 4.3.4.

Table 4.3.14 Main Gear Types Used for Prosecuting Each Species

Species	Gear Type
Cod	Gillnet, Bottom Otter Trawl, Hand Line, Longline, Trap Net
Redfish	Bottom Otter Trawl, Midwater Trawl
Atlantic Halibut	Longline, Gillnet, Bottom Otter Trawl.
American Plaice	Bottom Otter Trawl, Gillnet, Midwater Trawl
Yellowtail Flounder	Bottom Otter Trawl, Longline
Greenland Halibut	Gillnet, Bottom Otter Trawl, Longline
Monkfish	Gillnet, Bottom Otter Trawl
Swordfish	Longline
Capelin	Beach and Bar Seine, Purse Seine, Trap Net
Clams	Dredge
Cockles and Scallops	Dredge
Lobster	Pot
Northern Shrimp	Shrimp Trawl
Snow Crab	Pot
Lumpfish	Gillnet

Beach and Bar Seine, Purse Seine and Trap Net are all used to capture Capelin, which explains why they operate at similar times as we observed in the time analysis illustration for this species presented in section 3.3 above. The above table, Table 4.3.14 clearly illustrates that some species are prosecuted by one gear type only, as is the case with Shrimp, Clams, Cockles, Scallops, Lobster, and Snow Crab. This information is derived from average annual catch data for the years 1995-2005. In the next step we refine the analysis of the catch by examining annual values.

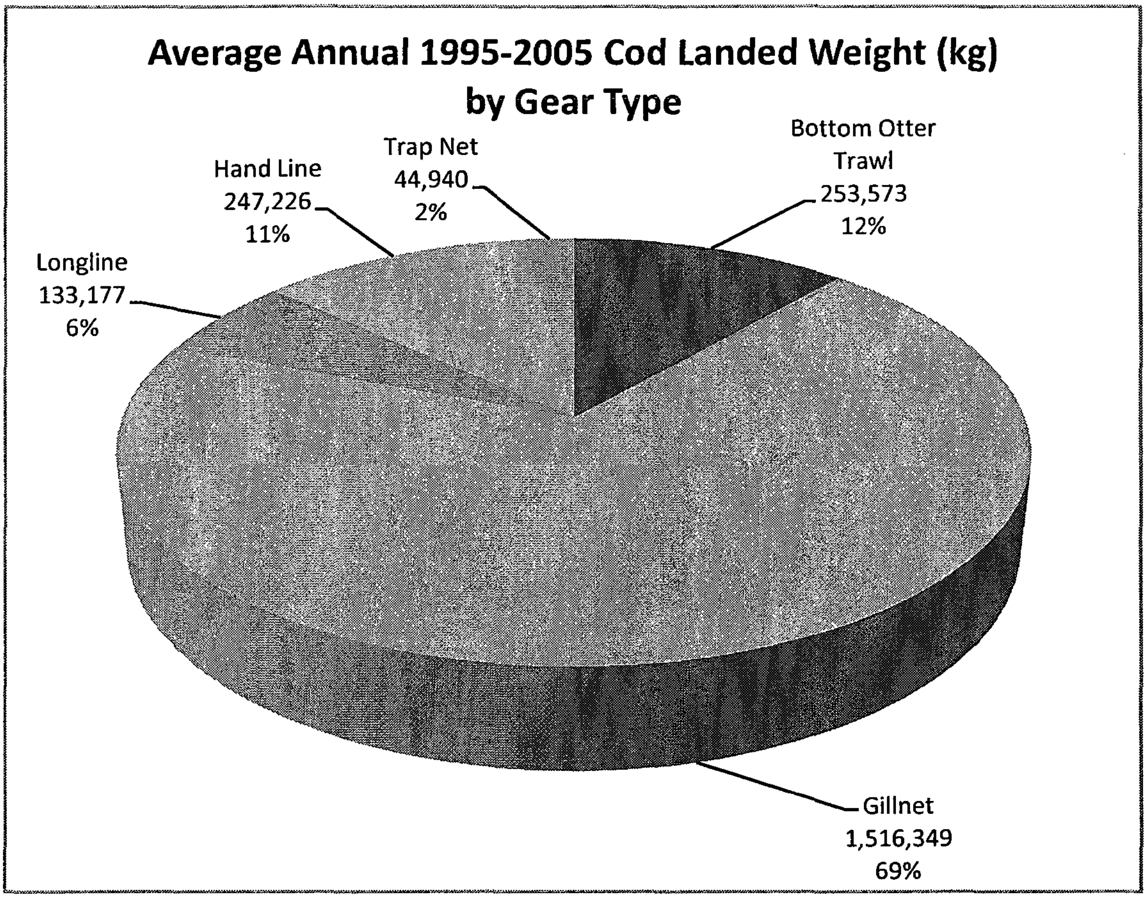

Figure 4.3.4 Average Annual Cod Landed Weight by Gear Type. Years 1995-2005.

4.3.7.1.1 Annual Catch by Gear Type For Each Species

We continue our analysis by examining the annual catch by gear type for each species. For those species that are only captured by one gear type, we can observe the evolution of the annual catch from 1995 to 2005, and, for those that are harvested by several gear types, we can also examine the relative proportion of catches by gear type for each species. Year-to-year variations can be very large, as illustrated in Figure 4.3.5 where Cod catches increase from under 300 tonnes in 1995 to over 5,000 tonnes in 1999. However, the relative proportion of landed weight of each gear type remains approximately the same every year (with the sole exception of Midwater trawlers that show exceptionally high catches of cod in 1999). Also, Bottom Otter Trawl is more active from 2000 through to 2005, and Shrimp Trawl only starts showing significant catches in the year 2000 and thereafter when shrimp catches on the Grand Banks expanded. The next step in the characterization of the Grand Banks fisheries consist of the analysis of the landed weight by species for each gear type.

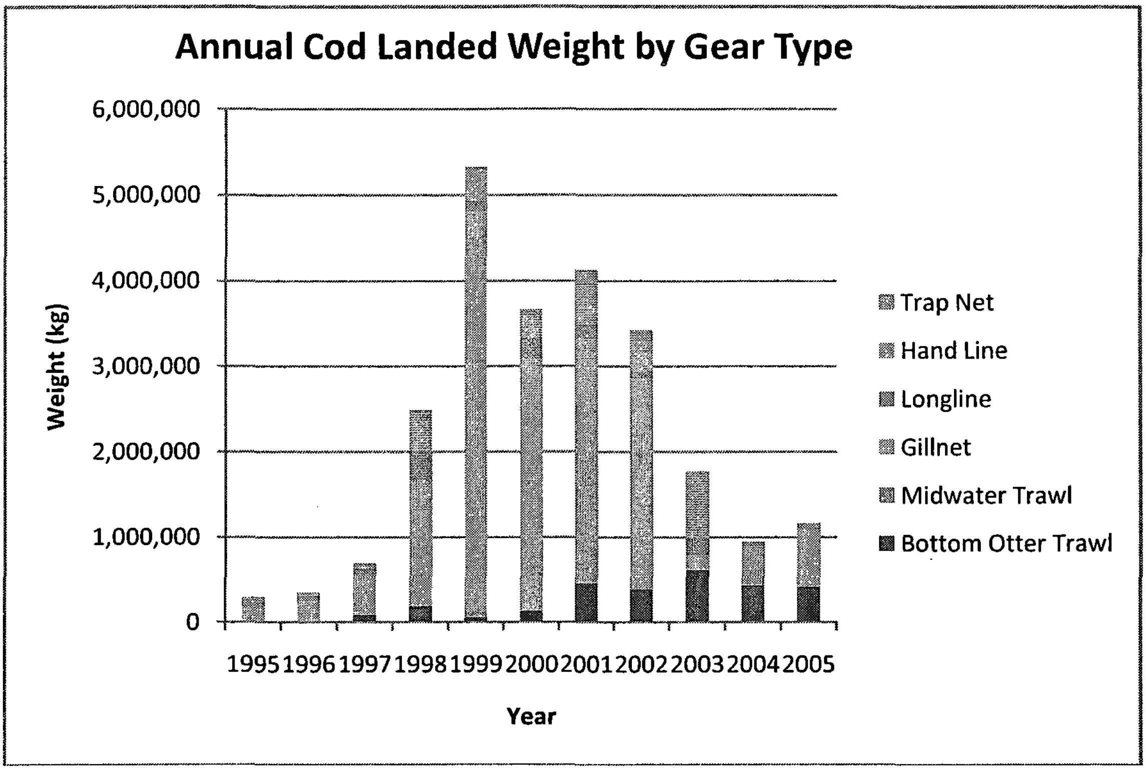

Figure 4.3.5 Annual Catch of Cod by Gear Type for Each Species. Years 1995-2005

4.3.7.2 Annual Catch by Species for each Gear Type

We continue our analysis of yearly landings by examining the relative proportions of each species caught for each gear type, e.g. the percentage of cod catches relative to the total landings of bottom otter trawlers. Table 4.3.15 shows the main species captured by each gear type.

Table 4.3.15 Significant Species Captured by Each Gear Type.

Gear Type	Species
Bottom Otter Trawl	Cod, Redfish, American Plaice, Yellowtail Flounder, Greenland Halibut
Midwater Trawl	Cod, Redfish, American Plaice, Yellowtail Flounder
Shrimp Trawl	Northern Shrimp
Beach and Bar Seine	Capelin
Purse Seine	Capelin
Gillnet	Cod, Atlantic Halibut, American Plaice, Greenland Halibut, Monkfish, Swordfish
Longline	Cod, Greenland Halibut, Swordfish
Handline	Cod
Trap Net	Capelin
Pot	Snow Crab, Lobster
Dredge	Clams, Cockles and Scallops

Some of the gear types are used to harvest one specific species, such as shrimp trawlers that harvest only Northern shrimp, whereas others are used to harvest a variety of species, notably gear types that prosecute groundfish, such as Gillnet in the example below (Figure 4.3.6).

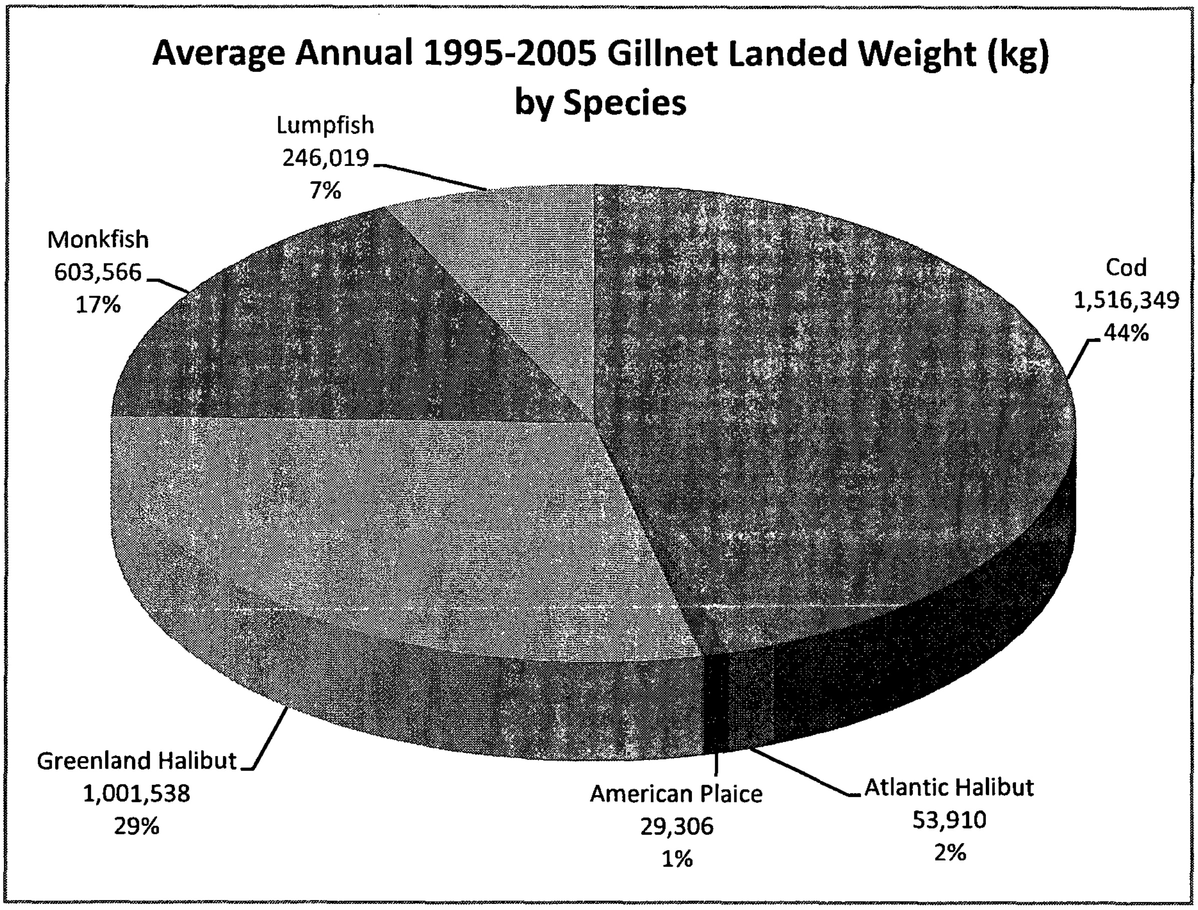

Figure 4.3.6 Average Annual Gillnet Landed Weight (kg) by Species. Years 1995-2005.

4.4 Further Data Filtering

In this section, we further our data filtering of the Grand Banks ZIFF dataset. Data filtering is carried out by the following steps:

- removal of Midwater Trawl as a gear type,
- exclusive use of data collected between 2000 to 2005 only,
- amalgamation of Clams, Cockles and Scallops into one species group (shellfish) and
- amalgamation of gear types that harvest Capelin only; Purse Seine, Beach and Bar Seine and Trap Net as one gear type.

These filtering decisions are analysed in further detail in the sections below.

4.4.1 Midwater Trawl

In 1999 there is a steep hike in catches of groundfish by Midwater trawl. A close examination of Yellowtail Flounder catches shows that, as a species, it is exclusively prosecuted by Bottom Otter Trawl in all years included in the study, excepting 1999 where just over 75% of total Yellowtail Flounder catches are captured by Bottom Otter Trawl. The remainder (25%) are recorded to be captured by Midwater trawl. This unexpected change could be explained if certain vessels in the fleet that would normally operate Bottom Otter Trawls switched to Midwater trawls for one year only (1999). Regardless of the cause, the portion of Midwater Trawl catches that show up in the ZIFF data, concerning average annual catches by species, originates from a single year, 1999, and is not representative of the typical gear type normally used to prosecute these species. This pattern of unusual Midwater Trawl catches in 1999 can also be clearly identified in the cases of Cod, Redfish, and American Plaice.

Midwater Trawl catches represent at most 6% of average annual catch by species when compared to other gear types. An examination of the figures of annual Midwater Trawl catches further illustrates the imbalance. Midwater Trawl catches reached a high of 4.9 thousand tonnes in 1999 which represents 92.7% of all Midwater trawl catches for the years 1995-2005, only to decrease to 41,734 kg in 2000 and zero for subsequent years. If we take into account the years 2000 to 2005, annual Midwater trawl catches average only 7 tonnes per year. This is not a significant amount compared to total annual catches and does not warrant inclusion as a significant gear type in our model, especially given the filtering of the years of interest as post-1999 (as described in the next section).

4.4.2 Using 2000-2005 data for the Model

The complete ZIFF dataset available for the Grand Banks analysis covers the years 1995-2005. However various major changes have taken place between 1995 and 1999 in the Grand Banks fisheries. Since the groundfish resource collapse and the subsequent moratorium of 1992, some fisheries have reopened and some stocks that were not previously harvested extensively have come under exploitation. For example, Yellowtail Flounder catches were nonexistent on the Grand Banks from 1995 to 1997 (in part due to the NAFO moratorium on this stock). Then, starting in 1998, close to 4,000 tonnes were landed. Catches remained between 9,000 and 12,000 tonnes from 2000 to 2005. Similarly, Shrimp catches only begin in earnest in 1999, becoming significant in the year 2000, where they accounted for 4 % of the total value of all landings in 3LNO.

Since the aim of this data analysis is to derive average values that are representative of the current situation, it is therefore logical to use data exclusively from the years 2000 to 2005 to drive the model as the pre-2000 period is clearly different from the post-2000 period for the reasons cited above. Table 4.4.1 below shows that the total cumulative value of the landings for the selected species accounts for 96.57% of all landings for the years 2000 to 2005.

Table 4.4.1 Cumulative Total Landed Value. Years 2000 to 2005.

Cumulative total 2000-2005			
Species	Value	Percentage	Rank
Snow Crab	$762,734,788	69.79%	1
Northern Shrimp	$73,286,310	6.71%	2
Yellowtail Flounder	$54,679,056	5.00%	3
Clams	$39,145,910	3.58%	4
Cod	$19,939,366	1.82%	5
Capelin	$15,644,457	1.43%	6
Greenland Halibut	$15,022,091	1.37%	7
Cockles and Scallops	$14,069,224	1.29%	8
Redfish	$11,785,677	1.08%	9
Swordfish	$10,995,285	1.01%	10
Monkfish	$9,124,187	0.83%	11
Atlantic Halibut	$8,337,849	0.76%	12
Lobster	$7,973,852	0.73%	13
Lumpfish	$6,581,992	0.60%	14
American Plaice	$6,110,382	0.56%	15
Total	$1,055,430,426	96.57%	

Thus, for the purpose of developing a representative model of the Grand Banks fishery in the current period, we use average values from the more representative years 2000 to 2005.

4.4.3 Amalgamation of Clams, Cockles and Scallops as one Species for the Model

The spatial analysis of Cockles, Surf Clams and Icelandic Scallop catches by Dredge gear reveal that these are prosecuted in areas 3Na, 3Nb, and 3Nd, representing 45.1%, 8.3% and 45.7% of Clam catches respectively, and 29.5%, 18.7% and 50.0% of combined Cockles and Scallop catches, respectively (see Figure 4.4.1). These three areas account for 99.1% of Clams and 98.2% of combined Cockles and Scallop catches. Furthermore, the time analysis of Dredge catches of Clams, Cockles and Scallop catches show similar dynamics (see Figure 4.4.2) throughout the fishing season on these species that takes up all weeks of the year. Due to these marked similarities, these species are amalgamated for the purpose of developing the fisheries performance model for the Grand Banks fishery.

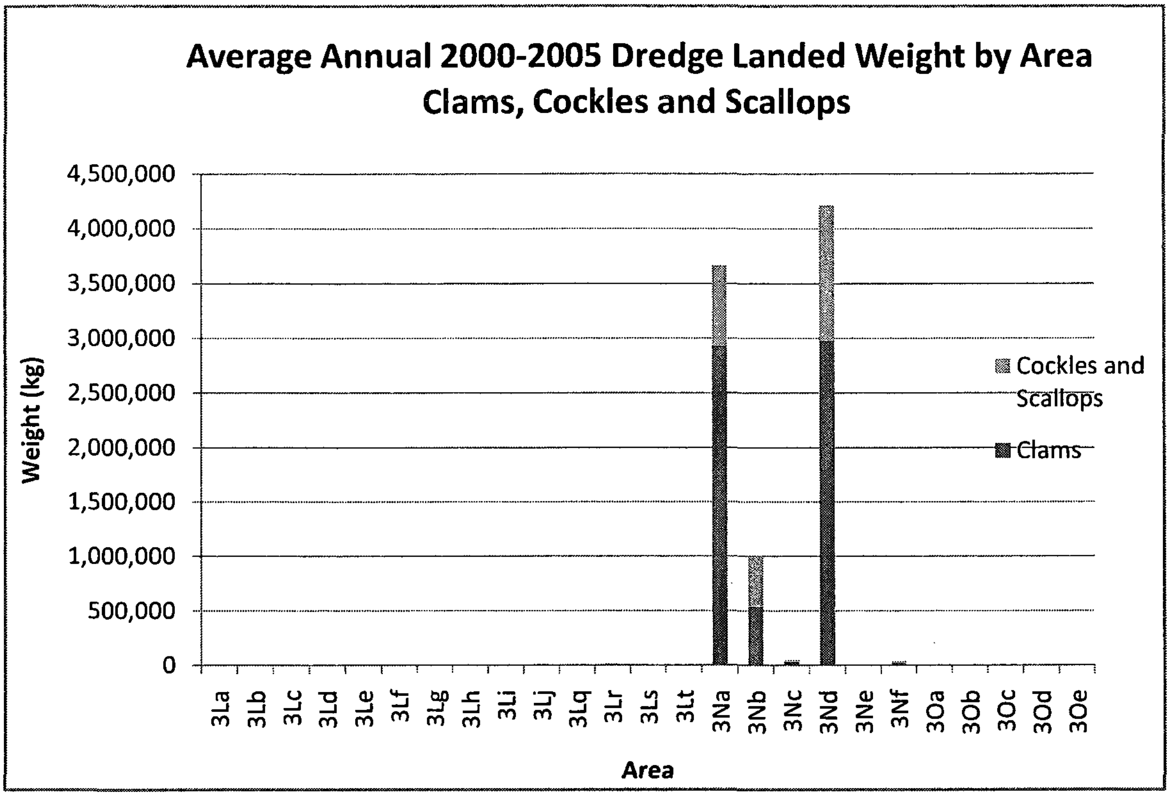

Figure 4.4.1 Average Annual Dredge Landed Weight by Area – Clams, Cockles and Scallops. Years 2000-05.

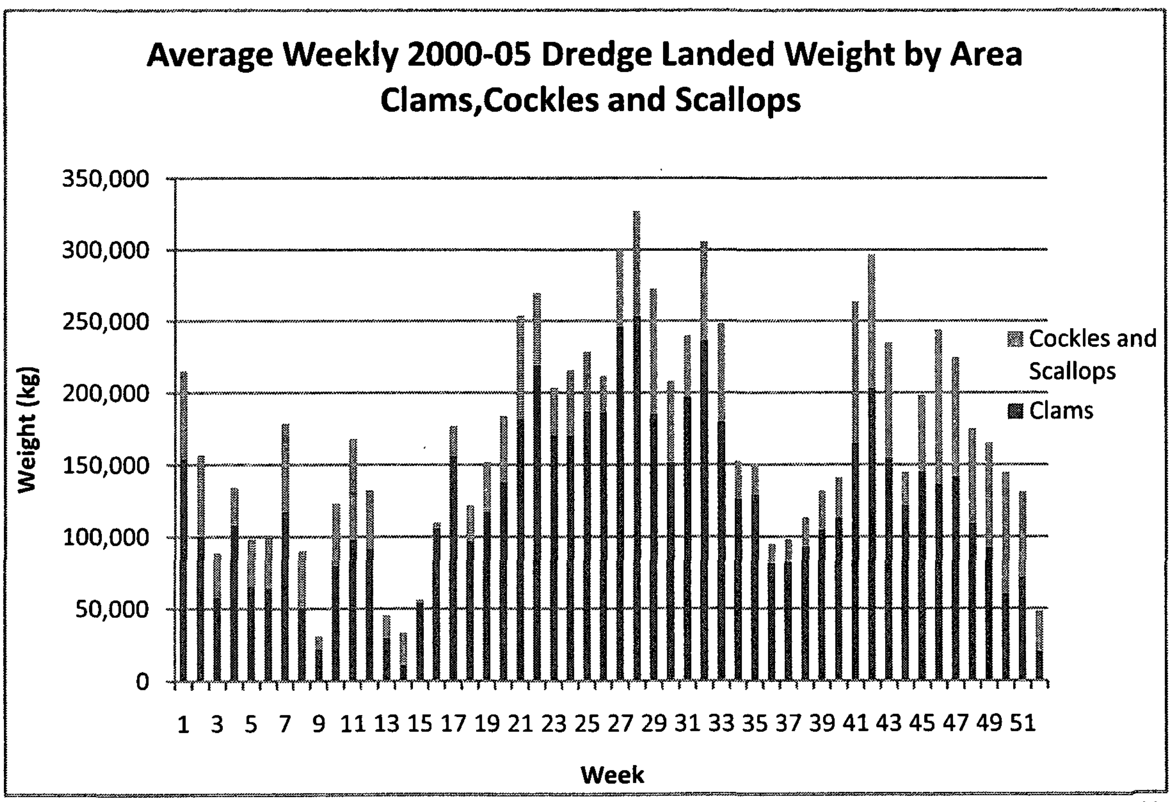

Figure 4.4.2 Average Weekly Dredge Landed Weight by Area. Clams, Cockles and Scallops. Years 2000-05

4.4.4 Amalgamation of Beach and Bar Seine, Purse Seine and Trap Net into one Gear Type

Average annual catches in the years 2000 to 2005 by Beach and Bar Seine, Purse Seine and Trap net of Capelin account for 100%, 100% and 99% of total catches by each of these gear types, respectively. As illustrated in Figure 4.4.3 and Figure 4.4.4, these three gear types are used in the same areas (3La, 3Lb and 3Lf), and at the same limited time of year (between weeks 26 and 31 of the calendar year). Given these similarities, these three gear types are considered as one gear exploiting the Capelin species for the model.

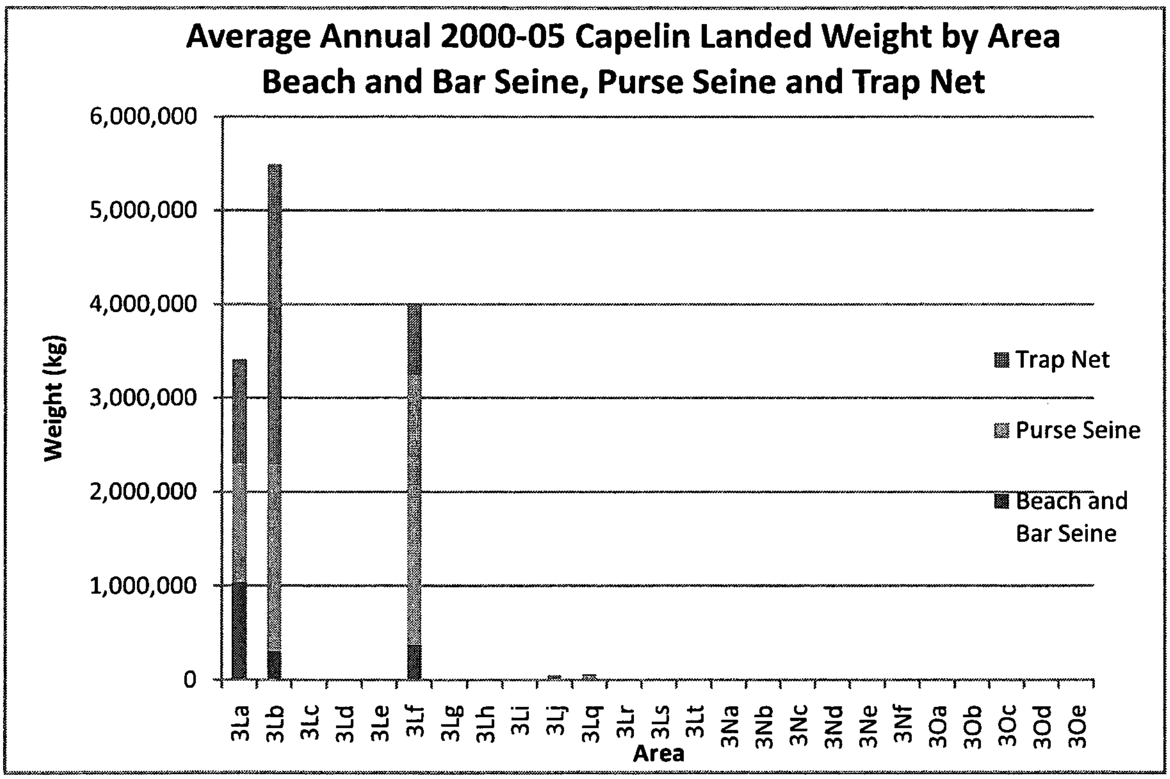

Figure 4.4.3 Average Annual Capelin Landed Weight by Area - Beach and Bar Seine, Purse Seine and Trap Net. Years 2000-2005.

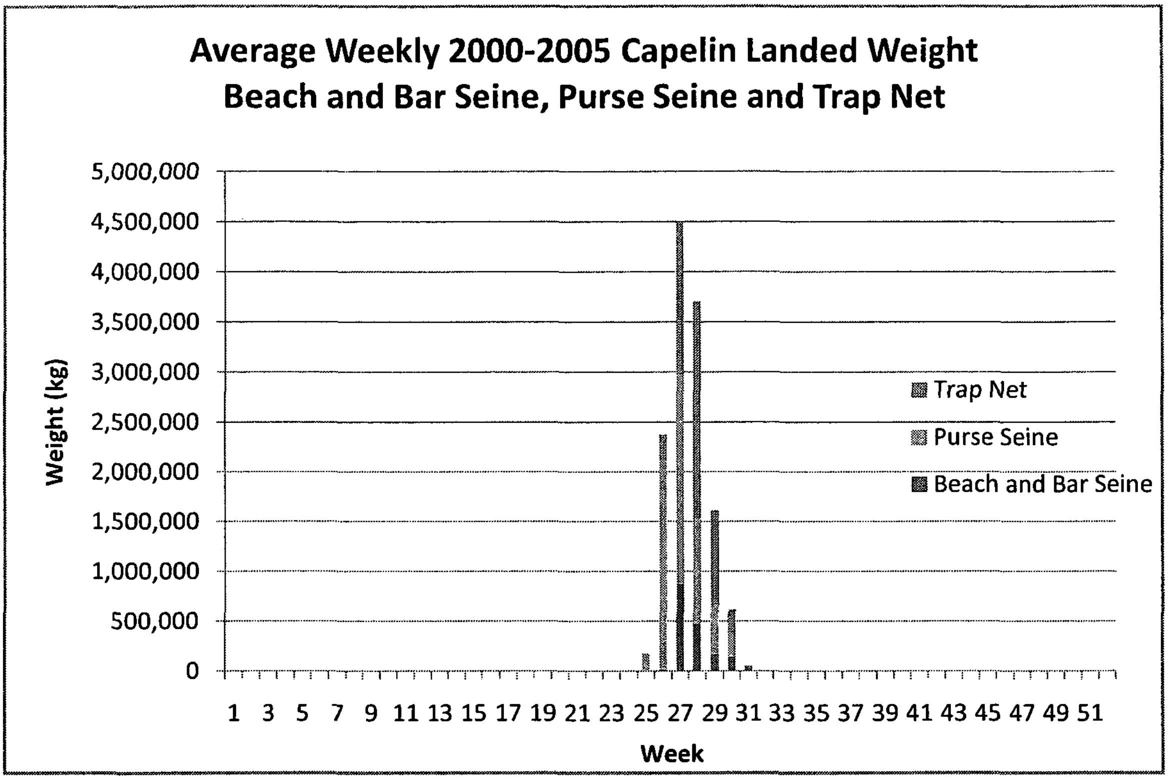

Figure 4.4.4 Average Weekly 2000-2005 Capelin Landed Weight - Beach and Bar Seine, Purse Seine and Trap Net

The data filtering adjustments described in subsections 4.4.1, 4.4.2, 4.4.3 and 4.4.4 result in a parsimonious number of species and gear types combinations without loss of pertinent information for describing the Grand Banks fleet activity and performance. We use this filtered dataset to identify the significant species and gear type combinations as described in the next section.

4.5 Identification of Species and Gear Type Combinations

Significant species and gear types combinations are selected by examining two sets of indicators, namely:

1. The proportion that each gear type represents of the total catch by species, and
2. The proportion that each species represents of the total catch by gear type.

Table 4.5.1. contains the information on the average annual catch for each species and gear type combination and this information is used to compute the two sets of indicators contained in Table 4.5.2 and Table 4.5.3. Table 4.5.2 below shows the average annual

percentage of the total catch by species that each gear type contributes, and Table 4.5.3 displays the proportion of average annual catch by gear type that each species represents. Finally, Table 4.5.4 lists the significant gear type and species combinations for the Grand Banks data used in the thesis.

Table 4.5.1 Average Annual Catch per Species and Gear Type. Years 2000-2005.

	Average Annual 2000-2005 Catch per Species and Gear Type								
	Bottom Otter Trawl	Shrimp Trawl	BB and P Seine, T Net	Gillnet	Longline	Hand Line	Pot	Dredge	Total
Cod	406,998	0	60,097	1,604,952	128,880	311,805	0	0	2,512,731
Redfish	3,572,364	1	0	1,694	0	40	0	0	3,574,099
Atlantic Halibut	12,772	0	0	64,126	122,777	0	0	0	199,674
American Plaice	1,276,459	0	0	28,818	174	12	0	0	1,305,461
Yellowtail Flounder	11,620,019	0	0	3,539	0	0	0	0	11,623,557
Greenland Halibut	726,658	0	0	1,158,001	67,766	29	0	0	1,952,453
Monkfish	7,335	0	0	967,390	547	0	0	0	975,272
Lumpfish	0	0	0	262,807	0	0	1	0	262,808
Swordfish	31	0	0	85	229,135	0	0	0	229,250
Capelin	0	0	13,013,829	0	0	0	0	0	13,013,829
Clams, Cockles and Scallops	0	0	0	0	0	0	0	8,974,878	8,974,878
Lobster	0	0	0	0	0	0	112,848	0	112,848
Northern Shrimp	0	7,907,508	0	0	0	0	0	0	7,907,508
Snow Crab	0	0	0	2	0	0	29,697,958	0	29,697,960
Total	17,622,633	7,907,510	13,073,926	4,091,412	549,277	311,886	29,810,807	8,974,878	82,342,328

Table 4.5.2 Average Annual Catch – Percentage of total Species Catch by Gear Type. Years 2000-2005.

Average Annual 2000-2005 Percentage of Total Catch by Species for each Gear Type									
	Bottom Otter Trawl	Shrimp Trawl	BB and P Seine, T Net	Gillnet	Longline	Hand Line	Pot	Dredge	Total
Cod	16%	0%	2%	64%	5%	12%	0%	0%	100%
Redfish	100%	0%	0%	0%	0%	0%	0%	0%	100%
Atlantic Halibut	6%	0%	0%	32%	61%	0%	0%	0%	100%
American Plaice	98%	0%	0%	2%	0%	0%	0%	0%	100%
Yellowtail Flounder	100%	0%	0%	0%	0%	0%	0%	0%	100%
Greenland Halibut	37%	0%	0%	59%	3%	0%	0%	0%	100%
Monkfish	1%	0%	0%	99%	0%	0%	0%	0%	100%
Lumpfish	0%	0%	0%	100%	0%	0%	0%	0%	100%
Swordfish	0%	0%	0%	0%	100%	0%	0%	0%	100%
Capelin	0%	0%	100%	0%	0%	0%	0%	0%	100%
Clams, Cockles and Scallops	0%	0%	0%	0%	0%	0%	0%	100%	100%
Lobster	0%	0%	0%	0%	0%	0%	100%	0%	100%
Northern Shrimp	0%	100%	0%	0%	0%	0%	0%	0%	100%
Snow Crab	0%	0%	0%	0%	0%	0%	100%	0%	100%

Table 4.5.3 Average Annual Catch – Percentage of total Gear catches by species. Years 2000-2005.

	Average Annual 2000-2005 Catch per Species and Gear Type						
	Cod	Redfish	Atlantic Halibut	American Plaice	Yellowtail Flounder	Greenland Halibut	Monkfish
Bottom Otter Trawl	2%	20%	0%	7%	66%	4%	0%
Shrimp Trawl	0%	0%	0%	0%	0%	0%	0%
BB and P Seine, T Net	0%	0%	0%	0%	0%	0%	0%
Gillnet	39%	0%	2%	1%	0%	28%	24%
Longline	23%	0%	22%	0%	0%	12%	0%
Hand Line	100%	0%	0%	0%	0%	0%	0%
Pot	0%	0%	0%	0%	0%	0%	0%
Dredge	0%	0%	0%	0%	0%	0%	0%

Table 4.5.3 Continued

	Swordfish	Capelin	Clams, Cockles and Scallops	Lobster	Northern Shrimp	Snow Crab	Lumpfish	Total
Bottom Otter Trawl	0%	0%	0%	0%	0%	0%	0%	100%
Shrimp Trawl	0%	0%	0%	0%	100%	0%	0%	100%
BB and P Seine, T Net	0%	100%	0%	0%	0%	0%	0%	100%
Gillnet	0%	0%	0%	0%	0%	0%	6%	100%
Longline	42%	0%	0%	0%	0%	0%	0%	100%
Hand Line	0%	0%	0%	0%	0%	0%	0%	100%
Pot	0%	0%	0%	0%	0%	100%	0%	100%
Dredge	0%	0%	100%	0%	0%	0%	0%	100%

Table 4.5.4 Significant Species and Gear Types Combinations of the Filtered Dataset

Bottom Otter Trawl	Cod
	Redfish
	Atlantic Halibut
	American Plaice
	Yellowtail Flounder
	Greenland Halibut
Shrimp Trawl	Northern Shrimp
Beach and Bar Seine, Purse Seine and Trap Net	Capelin
Gillnet	Cod
	Atlantic Halibut
	American Plaice
	Greenland Halibut
	Monkfish
	Lumpfish
Longline	Cod
	Atlantic Halibut
	Greenland Halibut
	Swordfish
Handline	Cod
Pot	Lobster
	Snow Crab
Dredge	Clams, Cockles and Scallops

4.6 Significant species and Gear Type combination catches by area

Section 4.3.5 of this text contains a spatial analysis of selected species and gear types for NAFO division 3L. Each of the divisions, 3L,3N, and 3O representing the Grand Banks area are divided into subdivisions identified by a letter suffix, i.e. 3L is divided into 3La, 3Lb, 3Lc, etc... (See Figure 3.3.1). These subdivisions are referred to as unit areas or units. Because the original data contain information on the origin of the catch by subdivision (See

Table 4.1.1), the spatial analysis can be refined to include catches by subdivisions and unit areas. The analysis can also be refined using the species and gear type combinations identified previously.

Table 4.6.1 summarizes the main harvesting areas for each selected species and gear type combination, as determined by the percentage of the catch weight by subdivision relative to the total for all areas. Those areas accounting for 2% or more of the total catch are selected and presented in this table.

Table 4.6.1 Percentage of Total Catch by Area, for each Significant Species and Gear Types Combinations – Area 3L

Percentage of Total Catch by Area															
Gear Type	**Species**	3La	3Lb	3Lc	3Ld	3Le	3Lf	3Lg	3Lh	3Li	3Lj	3Lq	3Lr	3Ls	3Lt
Bottom Otter Trawl	Cod														
	Redfish														
	Atlantic Halibut				2%										
	American Plaice				6%								3%		
	Yellowtail Flounder												3%		
	Greenland Halibut				100%										
Shrimp Trawl	Northern Shrimp			5%	7%	21%				66%					
BB Seine, P Seine and T Net	Capelin	26%	42%				31%								
Gillnet	Cod	36%	37%				9%				8%	7%			
	Atlantic Halibut														
	American Plaice	12%	15%	23%	19%		4%								
	Greenland Halibut	7%	12%	18%	27%	18%									
	Monkfish														
	Lumpfish	49%	29%				18%					3%			
Longline	Cod	14%	8%				4%				7%	8%			
	Atlantic Halibut														4%
	Greenland Halibut									2%					
	Swordfish														
Handline	Cod	11%	52%				12%				21%	5%			
Pot	Lobster	76%	15%				6%					3%			
	Snow Crab	4%	4%	14%	7%		4%	12%	7%	10%	5%	4%			8%
Dredge	Clams, Cockles and Scallops														

Table 4.6.1 (Continued) Areas 3N and 3O

Gear Type	Species	3Na	3Nb	3Nc	3Nd	3Ne	3Nf	3Oa	3Ob	3Oc	3Od	3Oe
Bottom Otter Trawl	Cod	3%		31%					15%	3%	40%	5%
	Redfish							4%		33%	9%	53%
	Atlantic Halibut			30%				5%		26%	12%	24%
	American Plaice	19%		43%					9%		18%	
	Yellowtail Flounder	18%		57%					8%		14%	
	Greenland Halibut											
Shrimp Trawl	Northern Shrimp											
BB Seine, P Seine and T Net	Capelin											
Gillnet	Cod											
	Atlantic Halibut							8%		52%	17%	23%
	American Plaice									5%	3%	16%
	Greenland Halibut									12%		6%
	Monkfish							9%		33%	36%	22%
	Lumpfish											
Longline	Cod			6%				9%		4%	21%	16%
	Atlantic Halibut			33%			2%	9%		14%	15%	20%
	Greenland Halibut									41%		50%
	Swordfish				8%		8%			27%	8%	47%
Handline	Cod											
Pot	Lobster											
	Snow Crab		7%			2%		2%	3%			
Dredge	Clams, Cockles and Scallops	41%	11%		47%							

The main harvesting areas are identified in Table 4.6.1. using a percentage of total catch for each species and gear type combinations. Appendix A contains all the graphics displaying the average annual catch weight by area for each combination. Figure 4.6.1 below gives an example of the catch by species by unit areas for the case of Northern Shrimp.

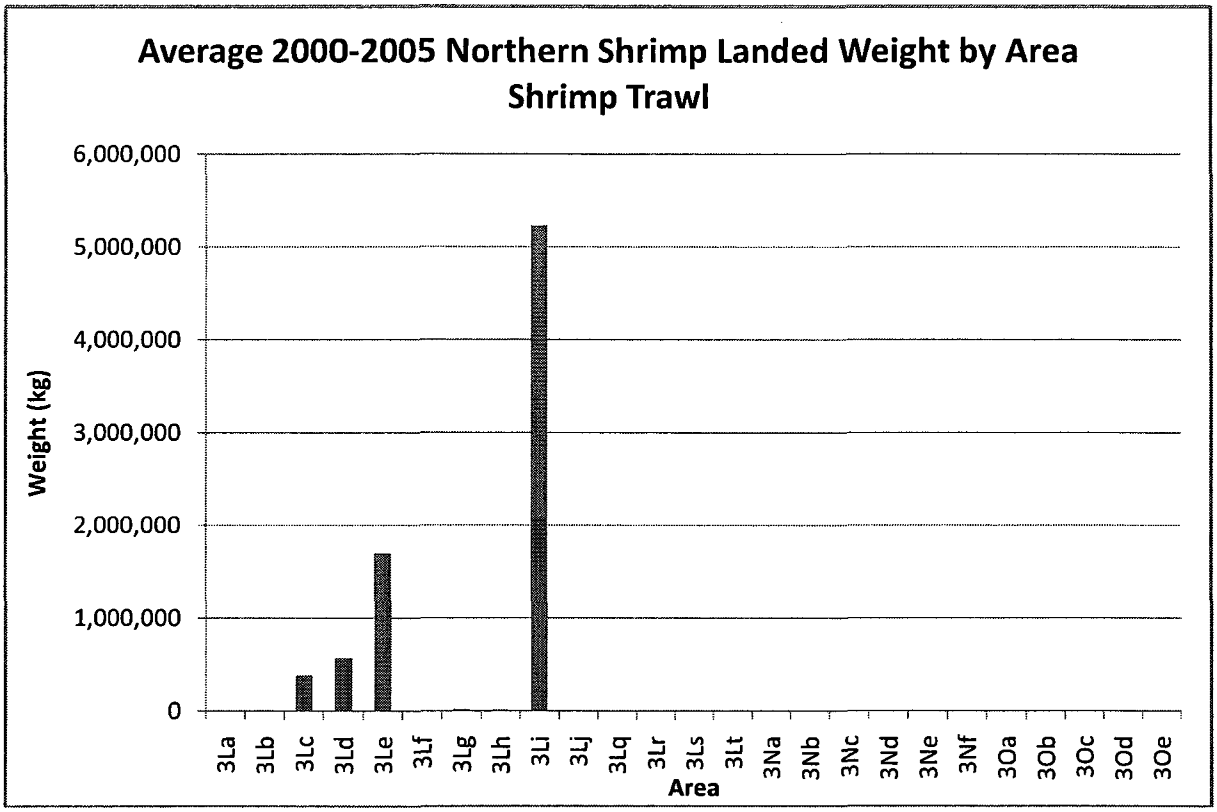

Figure 4.6.1 Average Northern Shrimp Landed Weight by Area – Shrimp Trawl. Years 2000-2005.

Most gear types operate in only three to five unit areas, except for Gillnet and Pot gears, both of which operate in inshore and offshore unit areas. Pot catches of Crab occur in all but five of the twenty-five subdivisions included in the study. However, a further step is needed before results of the analysis can be used in the model. This step will show that the average annual catch weights by area for each species and gear type combination are representative of annual values. The next two examples, Table 4.6.2 and Table 4.6.3 are representative of the high level of correlation of the catch by area and support the use of average annual values to describe the spatial component of the Grand Banks catches for the years 2000 to 2005.

Table 4.6.2 and Table 4.6.3 give the year-to-year correlation coefficient of the catch by unit area for two species, Northern shrimp and lobster. The coefficients are a measure of the repeating pattern of catches by area year after year, i.e. the relative spatial distribution of catches remain largely the same from year to year.

Table 4.6.2 Correlation Analysis. Year-to-year Northern Shrimp Catches by NAFO Subdivisions 3La to 3Oe

Shrimp Trawl	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	1.00	1.00				
2002	0.99	0.99	1.00			
2003	0.98	0.97	0.96	1.00		
2004	0.99	1.00	0.99	0.95	1.00	
2005	0.98	0.99	1.00	0.94	1.00	1.00

Table 4.6.3 Correlation Analysis. Year-to-year Lobster Catches by NAFO Subdivisions 3La to 3Oe

Lobster	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	1.00	1.00				
2002	1.00	1.00	1.00			
2003	1.00	1.00	1.00	1.00		
2004	1.00	1.00	1.00	1.00	1.00	
2005	1.00	1.00	1.00	1.00	1.00	1.00

4.6.1 Significant Species and Gear Type Combinations Weekly Catches

The seasonal component of harvesting activity by gear type was shown in section 4.3.6. Seasonal activity can now be identified for each significant species and gear type combination using average weekly landed weight for the years 2000 to 2005. The example of Swordfish catches by Longline (see Figure 4.6.2) illustrates the seasonality of the catch. The identified seasons of activity for each gear type and species combination are used in the implementation of our model. The correlation analysis of the weekly catches as illustrated in the case of Lobster (see Table 4.6.4) supports the use of average annual 2000-2005 catch values by gear and location to describe the current fishery.

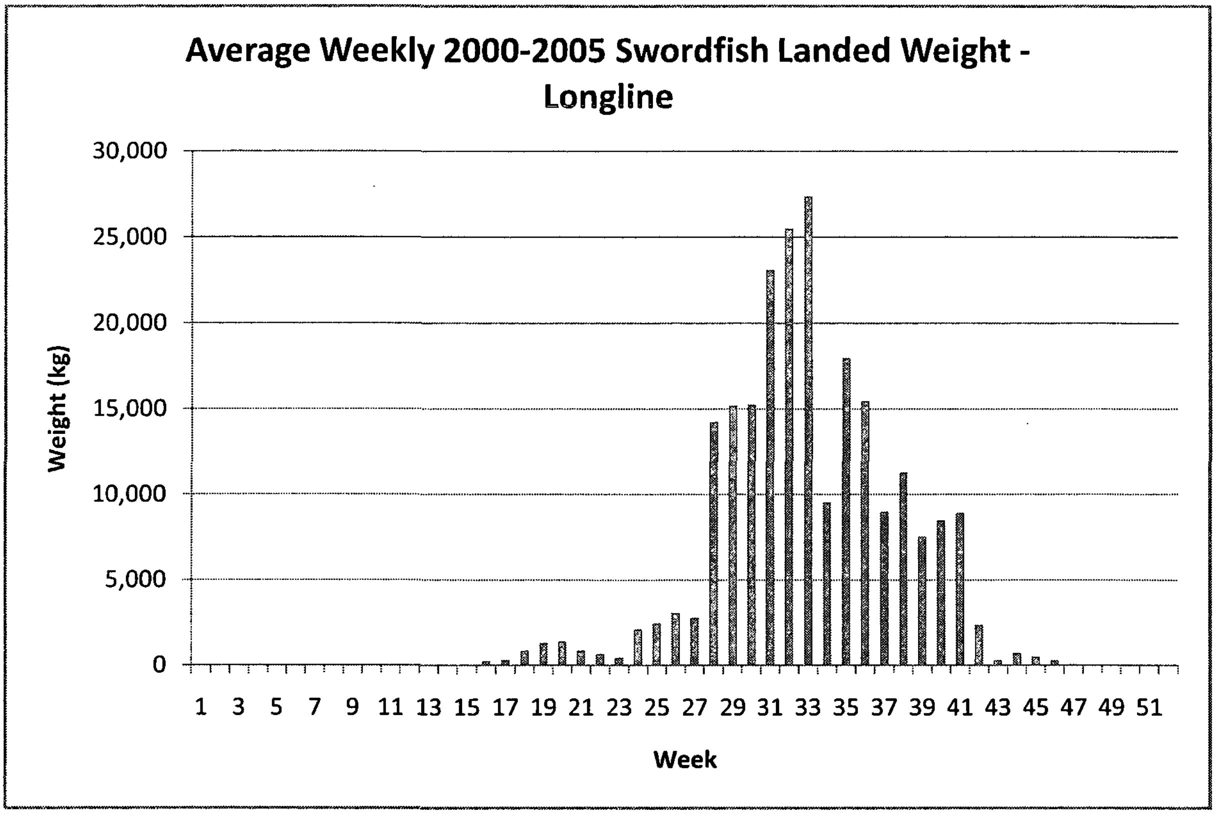

Figure 4.6.2 Average Weekly Swordfish Landed Weight - Longline. Years 2000-2005

Table 4.6.4 Correlation Analysis of Weekly Lobster Catches in Area 3Lb

Lobster	2005	2004	2003	2002	2001	2000
2005	1					
2004	0.92	1				
2003	0.66	0.81	1			
2002	0.93	0.93	0.73	1		
2001	0.79	0.86	0.88	0.76	1	
2000	0.72	0.72	0.63	0.72	0.79	1

4.7 Data Analysis Results

Based on the above analysis over all species, gears, weekly and area catches, a complete specification of the data can be determined. Appendix A - Data and Analysis provides the complete data analysis over all fishery components. The complete specification of location and time of activity for each species and gear type combination is listed in Table 4.7.1 and concludes our specification of the Grand Banks fishery data analysis used in the modelling exercise. The following chapter applies the LP model to the data specification and explores the performance of the models under alternative scenarios including comparisons with actual historical annualized data.

Table 4.7.1 Location and Time of Activity for each Gear Type and Species Combination

Gear Type	Species	Subdivisions	Weeks
Bottom Otter Trawl	Cod	3Na, 3Nc, 3Ob, 3Oc, 3Od, 3Oe	1, 13 to 23, 31 to 50
	Redfish	3Oa, 3Oc, 3Od, 3Oe	14 to 48
	Atlantic Halibut	3Ld, 3Nc, 3Oa, 3Oc, 3Od, 3Oe	12 to 49
	American Plaice	3Ld, 3Lr, 3Na, 3Nc, 3Ob, 3Od	11 to 23, 35 to 39
	Yellowtail Flounder	3Lr, 3Na, 3Nc, 3Ob, 3Od	1 to 23, 31 to 51
	Greenland Halibut	3Ld	11 to 32
Shrimp Trawl	Northern Shrimp	3Lc, 3Ld, 3Le, 3Li	1 to 5, 13 to 30, 35 to 40
Beach and Bar Seine, Purse Seine and Trap Net	Capelin	3La, 3Lb, 3Lf	26 to 30
Gillnet	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq	27 to 46
	Atlantic Halibut	3Oa, 3Oc, 3Od, 3Oe	1 to 9, 21 to 33,
	American Plaice	3La, 3Lb, 3Lc, 3Ld, 3Lf, 3Oc, 3Od, 3Oe	1 to 9, 19 to 41
	Greenland Halibut	3La, 3Lb, 3Lc, 3Ld, 3Le, 3Oa, 3Oc, 3Oe	19 to 40
	Monkfish	3Oa, 3Oc, 3Od, 3Oe	22 to 32
	Lumpfish	3La, 3Lb, 3Lf,	19 to 27
Longline	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq, 3Nc, 3Oa, 3Oc, 3Od, 3Oe	11 to 29, 36 to 47
	Atlantic Halibut	3Lt, 3Nc, 3Nf, 3Oa, 3Oc, 3Od, 3Oe	1 to 43
	Greenland Halibut	3Li, 3Oc, 3Oe	12 to 26, 30 to 46
	Swordfish	3Nd, 3Nf, 3Oc, 3Od, 3Oe	28 to 41
Handline	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq	13 to 16
Pot	Lobster	3La, 3Lb, 3Lf, 3Lq	18 to 28
	Snow Crab	3La, 3Lb, 3Lc, 3Ld, 3Le, 3Lg, 3Lh, 3Li, 3Lj, 3Lq, 3Lt, 3Nb, 3Ne, 3Oa, 3Ob	15 to 33
Dredge	Clams, Cockles and Scallops	3Na, 3Nb, 3Nd	Year-Round

4.8 Fleet Cost Structure

Implementing the model requires specifications on the catch, i.e. its location, time period, gear type, landed weight and landed value. These items have already been addressed in this chapter. Next in the requirements needed for the model are the costs associated with operating fishing vessels. Two sources are used to derive the values needed for the model implementation, DFO's 2004 Costs and Earnings Survey results and an internal report to DFO (Canada 2007i and Lane 2007). The former contains detailed information on the Newfoundland Crab and Shrimp vessels under 65' (19.8m) Length Overall (LOA). Values for Lobster and Capelin vessels under 65' LOA are derived from the Maritimes and the Bay of Fundy fleets, respectively. In the internal report, the cost structure is defined by three classes of vessel LOA; under 65', 65'to 100' (19.8m) and over 100'. Each is divided into fixed and mobile gear, except for vessels over 100' (30.5m). In the case where the vessel classes defined in Table 4.8.1 contain more than one class defined in the report such as longline vessels over 65', the final value is the sum of the weighted components for each vessel class. For example, the average annual 2000-2005 catch by longline vessels of 65' to 100' LOA and by vessels over 100' LOA represent 72% and 28% of the total for all vessels over 65', respectively. Therefore cost components of each fleet segment are multiplied by their corresponding weight to derive the longline fleet cost structure for vessels over 65' LOA. In the table, "Other" includes food, bait and ice.

Table 4.8.1 Grand Banks Fishing Fleet Cost Structure

Gear Type and Vessel LOA	Labour	Fuel, Oil and Grease	Other	Operating Cost to Revenue Ratio
Lobster < 25' (7.6 m)	0.69	0.09	0.23	0.47
Crab < 25'	0.65	0.14	0.21	0.47
Crab 25' to 65' (19.8m)	0.81	0.08	0.11	0.59
Crab > 65'	0.57	0.28	0.15	0.54
Dredge < 65'	0.75	0.14	0.11	0.53
Dredge > 65'	0.47	0.35	0.18	0.70
Capelin (All vessels)	0.74	0.10	0.17	0.47
Shrimp < 65'	0.64	0.25	0.11	0.56
Shrimp > 65'	0.47	0.35	0.18	0.70
Gillnet < 65'	0.74	0.10	0.17	0.47
Gillnet > 65'	0.35	0.37	0.28	0.61
Hand Line (All Vessels)	0.74	0.10	0.17	0.47
Longline < 65'	0.74	0.10	0.17	0.47
Longline > 65'	0.38	0.36	0.26	0.63
Bottom Otter Trawl < 100' (30.5m)	0.58	0.26	0.15	0.54
Bottom Otter Trawl > 100'	0.47	0.35	0.18	0.70

5 Model Analysis

This chapter presents the implementation of the model formulated in the methodology described in Chapter 3 using the results of the data analysis performed in Chapter 4 above. The resulting model and validated results are also used for scenario analysis of changes in economic conditions and other changes anticipated in the fishery. Results in the form of economic performance and vessel deployment and operations are given for each relevant gear type and species combination in the Grand Banks fishery as described in detail in the data analysis of Chapter 4. In the current chapter, we further refine the results for each gear type and species combination by dividing them into separate vessel Length Overall (LOA) categories where significant differences exist as noted below to improve model validation.

5.1 Terminology

In order to clearly identify the results we refer to each model subset by the species captured. When a gear type harvests several species, the main species is used to identify the model subset. For example, the "Crab Model" refers to crab and lobster harvested by pot. Groundfish refers to all groundfish species and their associated gear types, with the addition of swordfish. The summary of all subsets representing the full spectrum of the Grand Banks fishery is found in **Table 5.1.1** below.

Table 5.1.1 Model Subsets

Model Name	Gear Type	Species	Vessel Subgroups
Capelin	Purse Seine, Beach and Bar Seine, Trap Net	Capelin	All Vessels
Clams	Dredge	Clams, Cockles and Scallops	LOA<65' LOA>100'
Crab	Pot	Lobster, Snow Crab	LOA<25' 25'<LOA<65' LOA>65
Shrimp	Shrimp Trawl	Northern Shrimp	LOA<65' LOA>100'
Groundfish Inshore	Gillnet Longline Handline	Groundfish Groundfish, Swordfish Groundfish	LOA<65', Inshore LOA<65', Inshore All Vessels, Inshore
Groundfish Offshore	Bottom Otter Trawl	Groundfish	LOA<100', Offshore LOA>100', Offshore
	Gillnet	Groundfish	LOA<65', Offshore LOA>65', Offshore
	Longline	Groundfish, Swordfish	LOA<65', Offshore LOA>65', Offshore

Each set of model results and output are clearly identified throughout according to the definitions listed below:

1) **Historical**: Average annual gross operating income from historical data for the years 2000-2005. Results for this analysis take into account those gears, species and location combinations that are defined for the modelling analysis of the grand Banks fishery as described in Table 5.1.1. The results of this analysis are compared and validated against the full ZIFF dataset.
2) **Model**: Results obtained from the formulated LP model with constraints on catch and fleet size by location and period that correspond to historical values. The results of this model are compared and validated against the full ZIFF dataset as a means of estimating the relative performance efficiency of the fishery.
3) **Relaxed**: Results are obtained to reflect actual catches but with the "historical" constraints on fleet size relaxed by re-setting the upper bound on the number of vessels by period equal to the maximum for all periods and an upper bound on the number of vessels by area equal to the maximum for all areas. Both upper bounds are set for each relevant combination of species and gear types as per Table 5.1.1. This analysis maximizes the available value inherent in the actual fishery system and provides an upper bound on the performance of the system that could be obtained with full information about the price dynamics of the system.
4) **Baseline**: This version is similar to the relaxed model but includes operating costs in the objective function so that the overall objective is to maximize estimated Net Operating Income versus maximizing landed value from harvesting. The results of fleet deployment and operations under the "baseline" re compared with the historical, and relaxed results.
5) **Scenarios**: The Net Operating Income objective function and response is investigated when the analysis is subjected to "shocks'. These shocks simulate changes in real economic conditions such as the modification of fuel costs (as experienced in the oil price rise of 2008), changes to the market prices of landed fish (attributed to many products as part of the current global economic crisis since 2008) and labour costs fluctuations. Each of these adjustments are presented as scenarios that modify the

objective function and performance of the Grand Banks fishery model. These scenarios are defined in detail in Table 5.6.1 below.

Assumptions made with respect to the model and its inputs are discussed in the next section.

5.2 Model Assumptions and Inputs

The following LP model data parameters are derived for each combination of gear type, vessel class, species, area and time period (week) where vessel activity is recorded. These data are based on average weekly 2000-2005 historical values for the Grand Banks fishery:

1) Price per kg
2) Catch weight (landings in kg)
3) Number of active vessels available for deployment
4) Catch per vessel (in kg)
5) Vessel activity (location and timing of vessel average weekly fishing effort)
6) Operating cost (including fuel, labour, provisions)

The number of active vessels during each time period is based on the number of records in the ZIFF database with unique Commercial Fishing Vessel (CFV) numbers. Weekly catch per vessel is determined from weekly catch weight and the number of active vessels during the specified period. The information contained in the ZIFF database on days fished is incomplete, particularly in the case of crab and Lobster; therefore a different indicator of vessel operation time is necessary in order to estimate operating costs. We use average weekly catch per vessel as an indicator of time spent fishing. From the set of available catch per vessel values, we exclude the top 5% to remove outliers, and map the remaining values onto days of fishing activity in a week. The level of activity is then used to compute weekly operating costs by vessel by multiplying it with the estimated weekly cost for an average vessel. The number of vessels allocated to each time and location combination multiplied by the corresponding objective function coefficient determines the value of the objective function, which the LP algorithm seeks to maximize. When operating costs are assumed equal to zero, as is the case in section 5.3 below, the objective function corresponds to gross operating income or total harvest revenue (landed value). Once costs are included in the model, the objective function corresponds to net operating income landed value less operating costs).

We limit catch levels for each species and gear type combination to average values for the most recent 2000-2005 period.

Regarding the presentation of results, groundfish vessels are divided into two categories: small and large vessels, corresponding to vessels of LOA under 65' (19.8m) and vessel over 65'. The exception being that of Bottom Otter Trawl where vessels between 65' and 100' (30.5m) are also included in the small vessel category. However, these vessels only account for a quarter of catch weight of all bottom otter trawl vessels under 100'.

Inshore areas are defined as NAFO subdivisions within the area of study that are adjacent to the coastline, i.e. 3La, 3Lb, 3Lf, 3Lj, 3Lq. Offshore areas comprise all remaining NAFO subdivisions included in the study. (See also Figure 3.3.1)

5.3 Model Validation

The first part of the Grand Banks modelling analysis consists of comparing historical performance data with the LP model results for the purpose of validating the LP model framework. These results are presented in detail below for groundfish and overall results are presented for all gear types.

5.3.1 Comparison by Vessel Numbers

Figure 5.3.1 shows that the number of inshore groundfish vessels determined by the LP model closely matches annual average historical data for the 2000-2005 period. The inshore groundfish fleet is composed of gillnet, handline and longline vessels. The occurrence of limited activity from week 14 to 17 corresponds to the first season of handline gear operation. On week 24, the first peak of inshore groundfish harvesting is attributed to gillnet catches of Lumpfish, and the second peak to gillnet capture of Cod and Greenland Halibut. The third and final peak of the inshore fishery originates mainly from gillnet, longline and handline harvests of Cod. Regarding the location of inshore vessel activity as seen on Figure 5.3.2, subdivisions 3La and 3Lb exhibit the highest number of vessels, followed by 3Lf, 3Lj and 3Lq in decreasing order. The number of vessels by period corresponds to the sum of active vessels by period. Vessels that operate across several areas are counted for every location in which they are active.

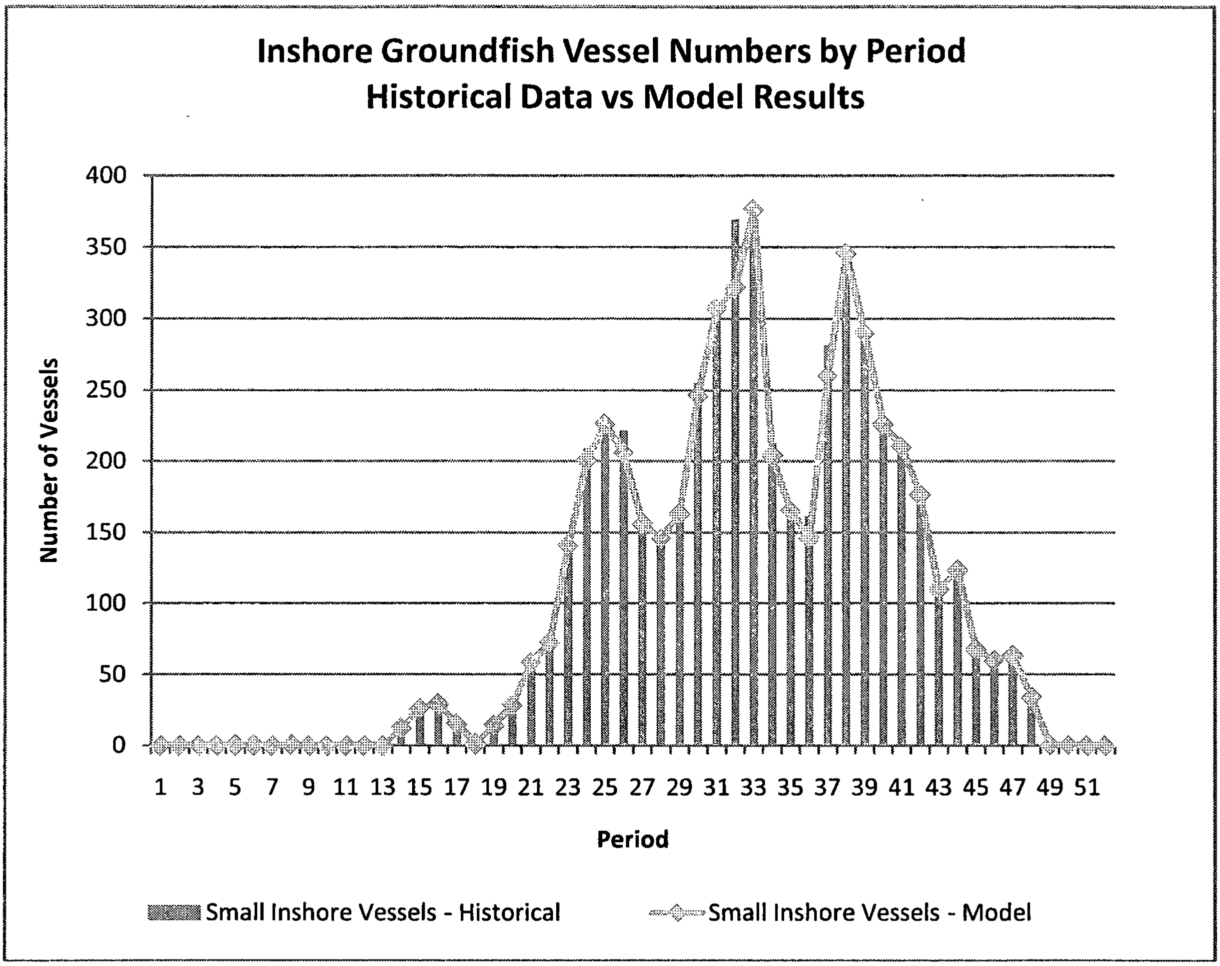

Figure 5.3.1 Inshore Groundfish Vessels Numbers – Historical vs Model

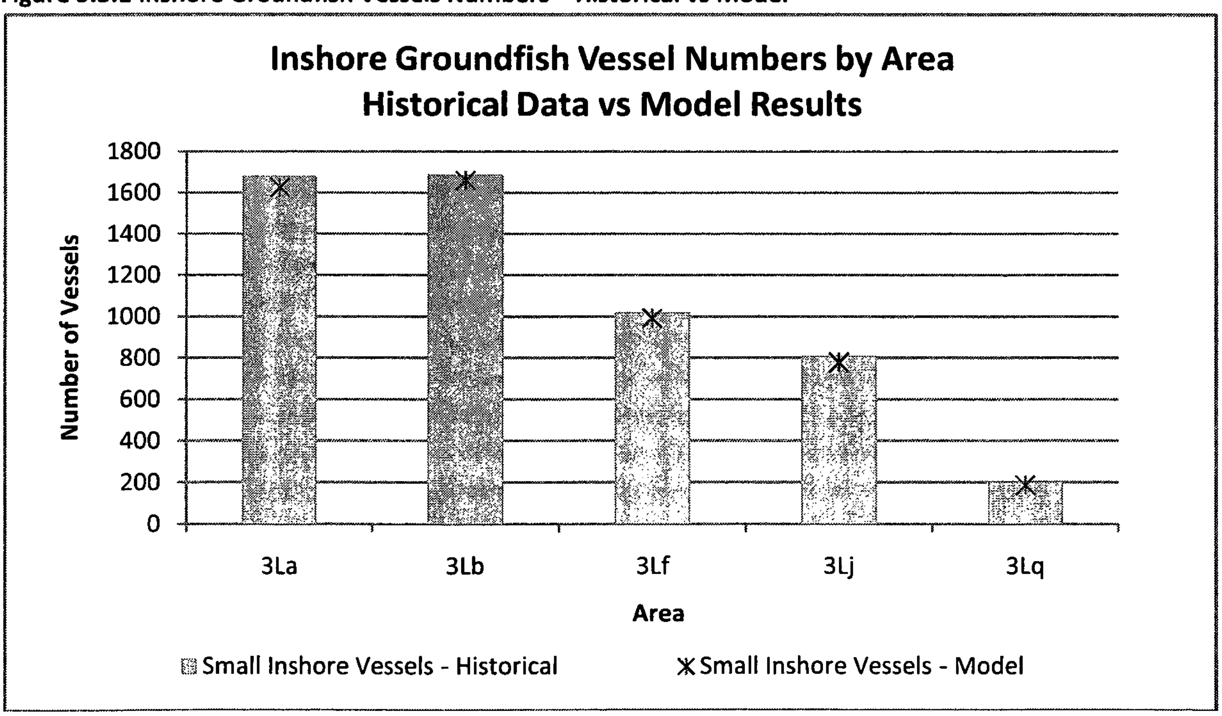

Figure 5.3.2 Inshore Groundfish Vessels by Area – Historical vs Model

We continue our analysis with the examination of offshore groundfish vessels by period. Figure 5.3.3 shows that large offshore vessels operate during two seasons; the first from week 11 to week 25, the second from week 34 to week 51, with peaks at week 19 and week 41, respectively. As noted above, small offshore vessels are active between the two peaks of large vessel activity, between weeks 22 and 42, with a peak at week 26. This can be explained by the fact that large vessels take advantage of better catches that occur in the spring and the fall because they can operate in inclement weather conditions that often occur during these two seasons, whereas small vessels operate mainly during the summer when weather conditions are better. With regards to offshore groundfish vessel distribution by area Figure 5.3.4), harvesting activity is clearly limited to a small subset of the NAFO unit areas included in our study. These vessels operate mainly on the Southwest portion of the Grand Banks and on the Northern edge to a lesser extent. Vessel numbers as determined by the LP model are similar to historical data, except for unit areas 3Oc and 3Od where model numbers are visibly lower. Cumulative numbers of inshore and offshore vessels by period (Figure 5.3.5) show that the inshore fleet is much larger than the offshore fleet, although the average annual value of landings from the inshore fleet represents less than one fifth of all groundfish landings.

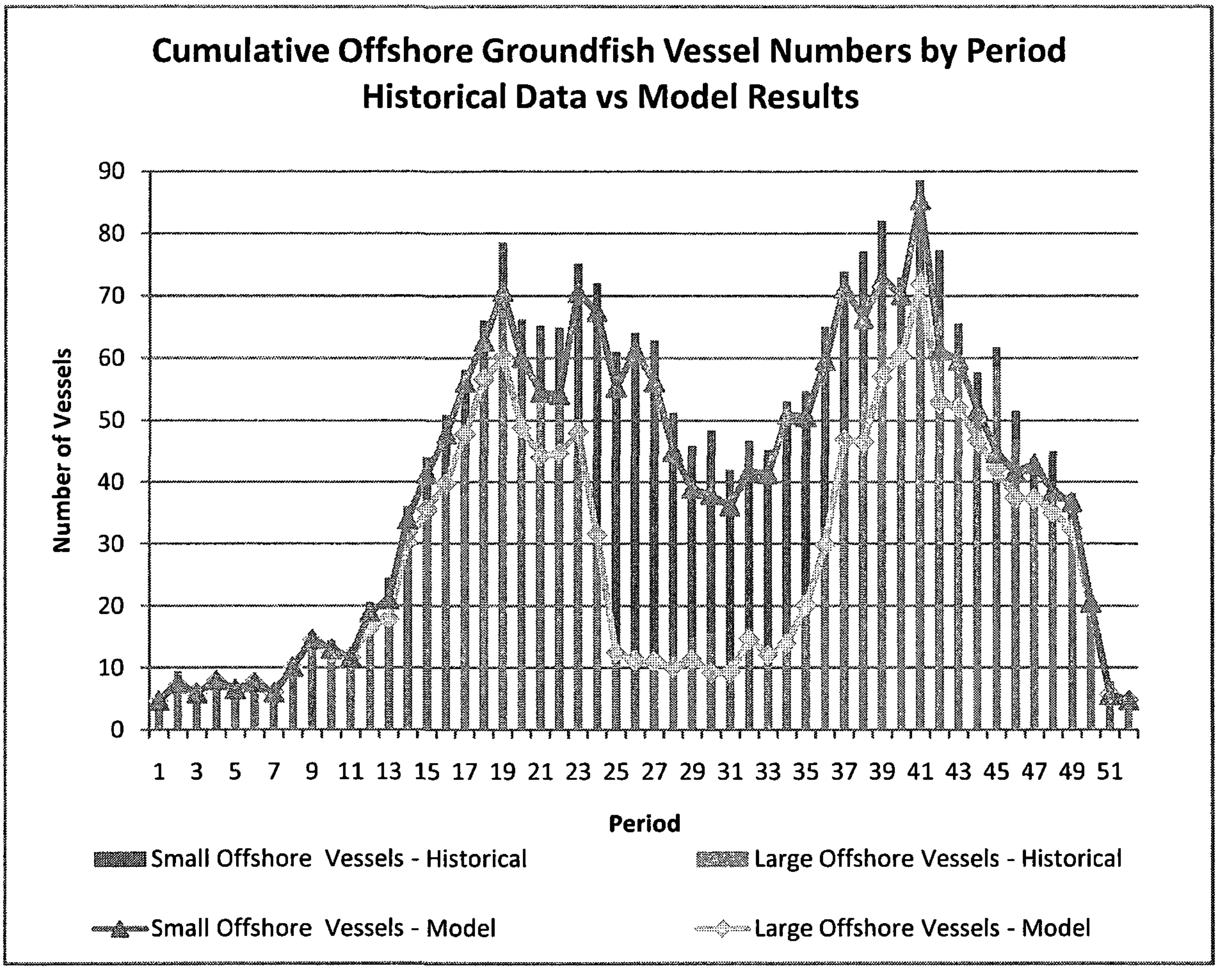

Figure 5.3.3 Offshore Groundfish Vessels - Historical vs Model

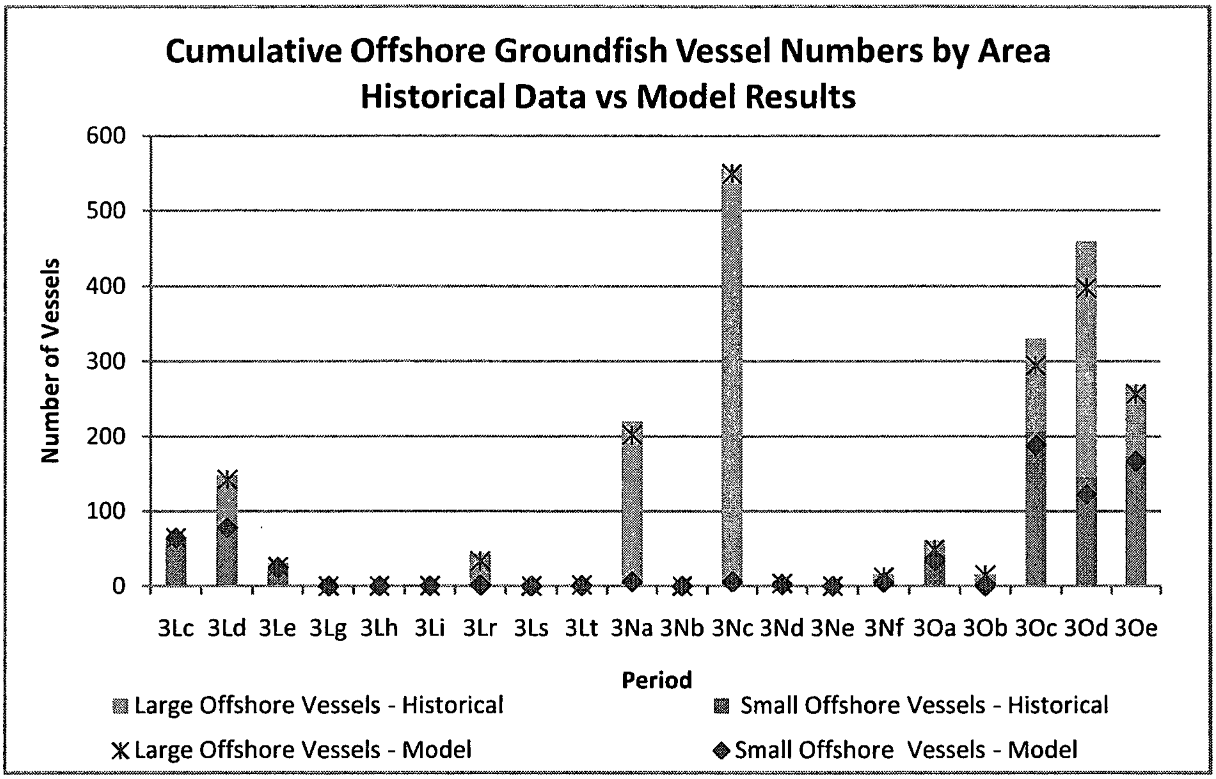

Figure 5.3.4 Offshore Vessels by Area - Historical vs Model

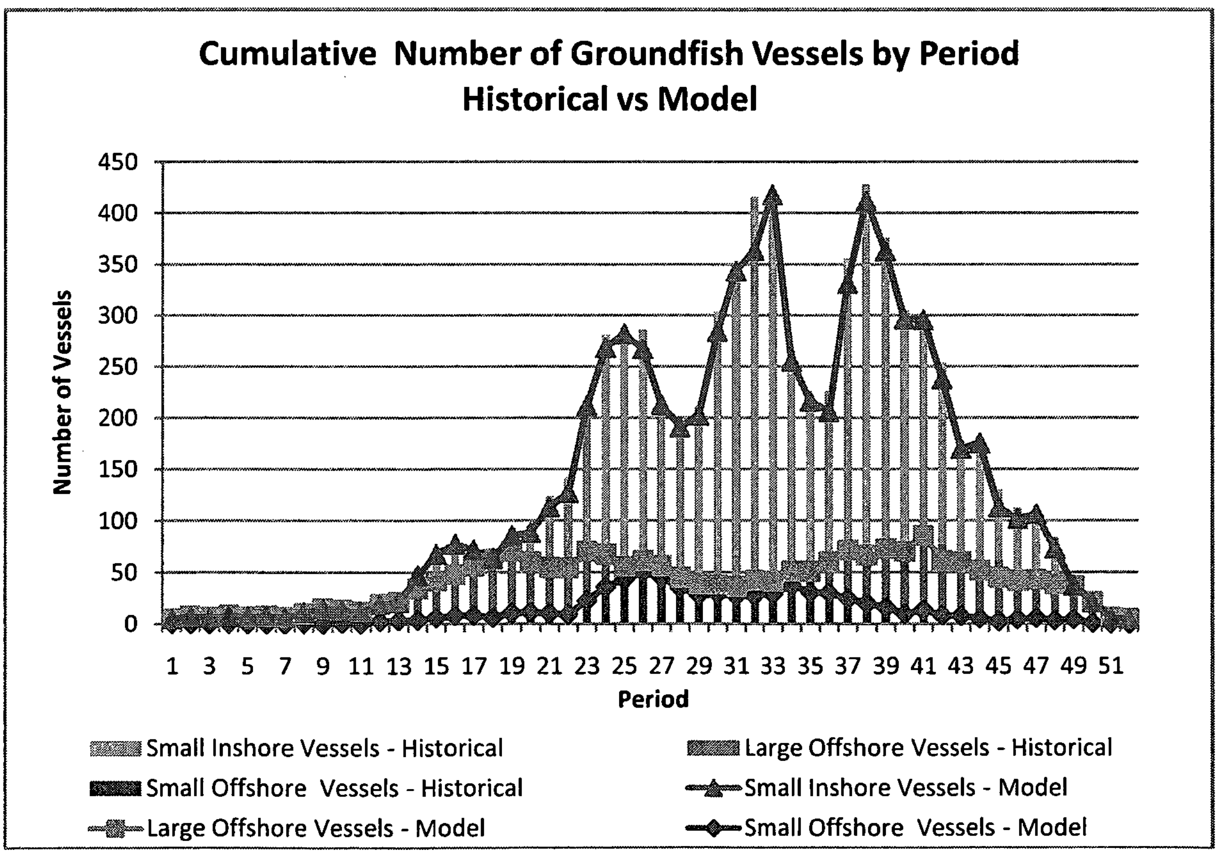

Figure 5.3.5 Cumulative Number of Groundfish Vessels - Historical vs Model

In Figure 5.3.6 the cumulative number of all vessels shows the relative sizes of the different fleets, the crab fleet being significantly larger than any other fleet. Its main season starts at week 15 and ends at week 35. Figure 5.3.6 also demonstrates that the number of vessels determined by the model closely matches the numbers according to historical data, except for periods 32 and 33. From the groundfish examples noted above, we can see that the number of vessels given by the model is approximately equal to that of historical data. The LP model allocates the catch to vessels so as to maximize gross operating income. We define this as the product of the average weekly catch per vessel and the price per landed kg of fish. The LP algorithm allocates vessels to locations and periods with higher average catch per vessel and higher relative prices, potentially requiring fewer vessels for the same catch. This explains why some of the vessel numbers given by the model are less than that of historical data while resulting in higher gross operating income as examined in section 5.3.2. Cumulative inshore vessel numbers by area (Figure 5.3.7) show that crab and groundfish vessels each account for close to half of the total. Unit area 3La exhibits the greatest number of vessels followed in decreasing order by 3Lb, 3Lf, 3Lj and 3Lq. Regarding offshore vessel numbers by location, crab vessels dominate NAFO division 3L (Figure 5.3.8) and cover the most unit areas of all vessels types included in our study. Shrimp vessels have a strong presence in area 3Li, and areas 3Lh, 3Ne and 3Nf show little to no activity. Total vessel numbers as allocated by the LP model are similar to corresponding historical data, except for 3O where there are visibly less vessels as determined by the LP model.

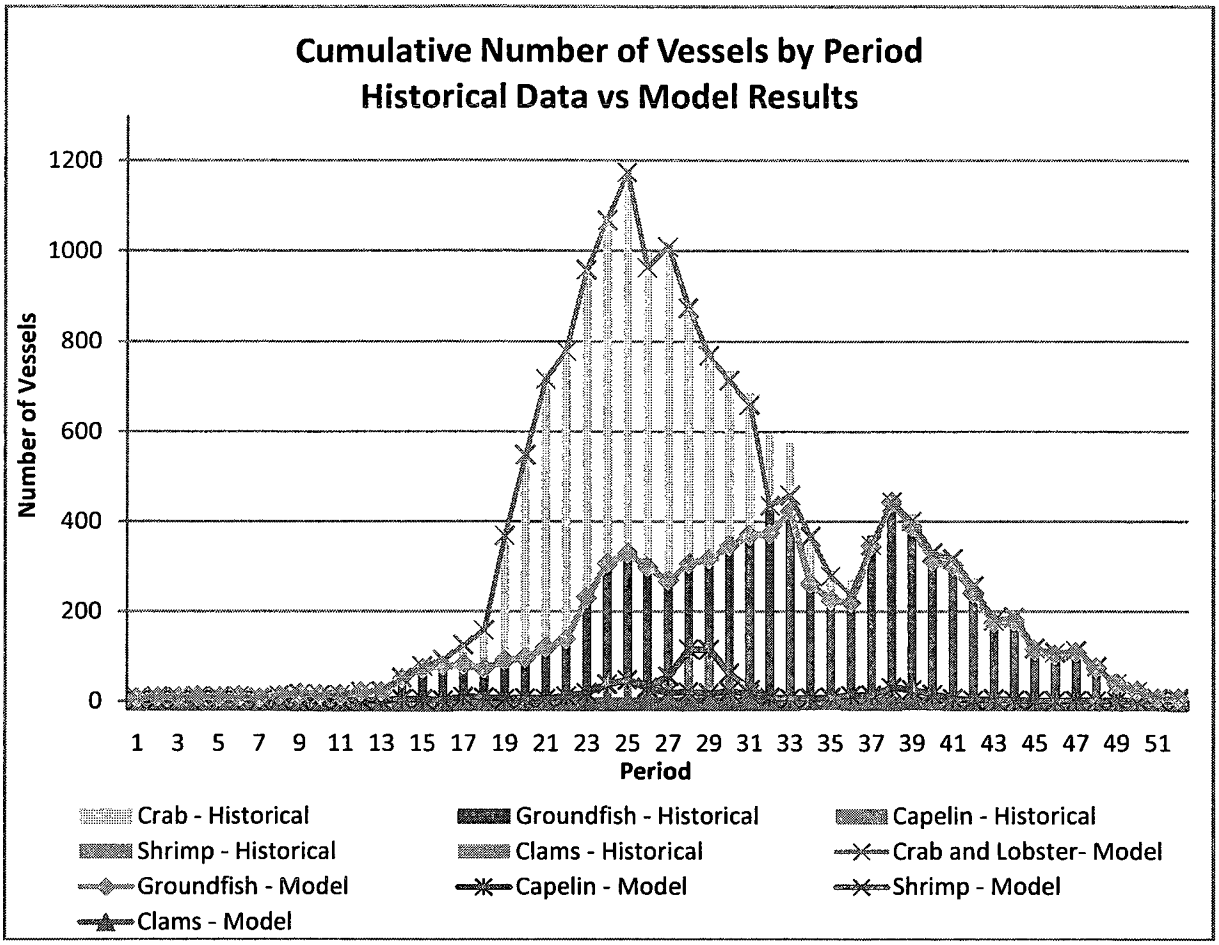

Figure 5.3.6 Cumulative Number of Vessels by Period - Historical vs Model

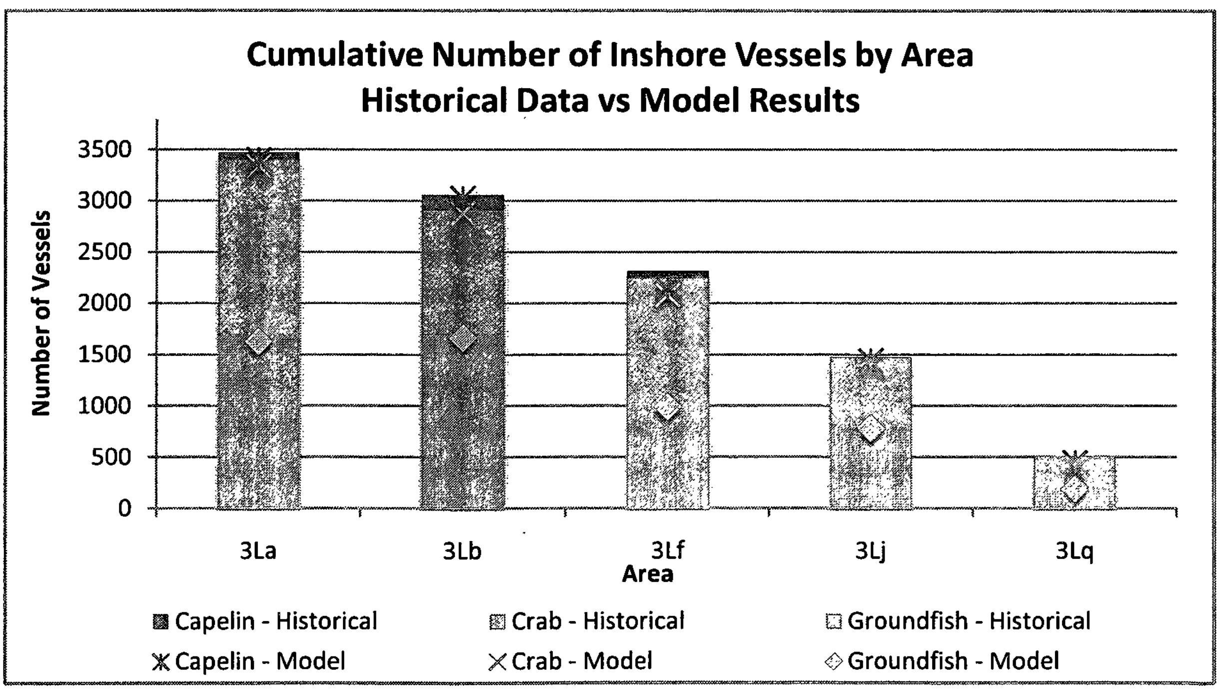

Figure 5.3.7 Cumulative Number of Inshore Vessels by Area - Historical vs Model

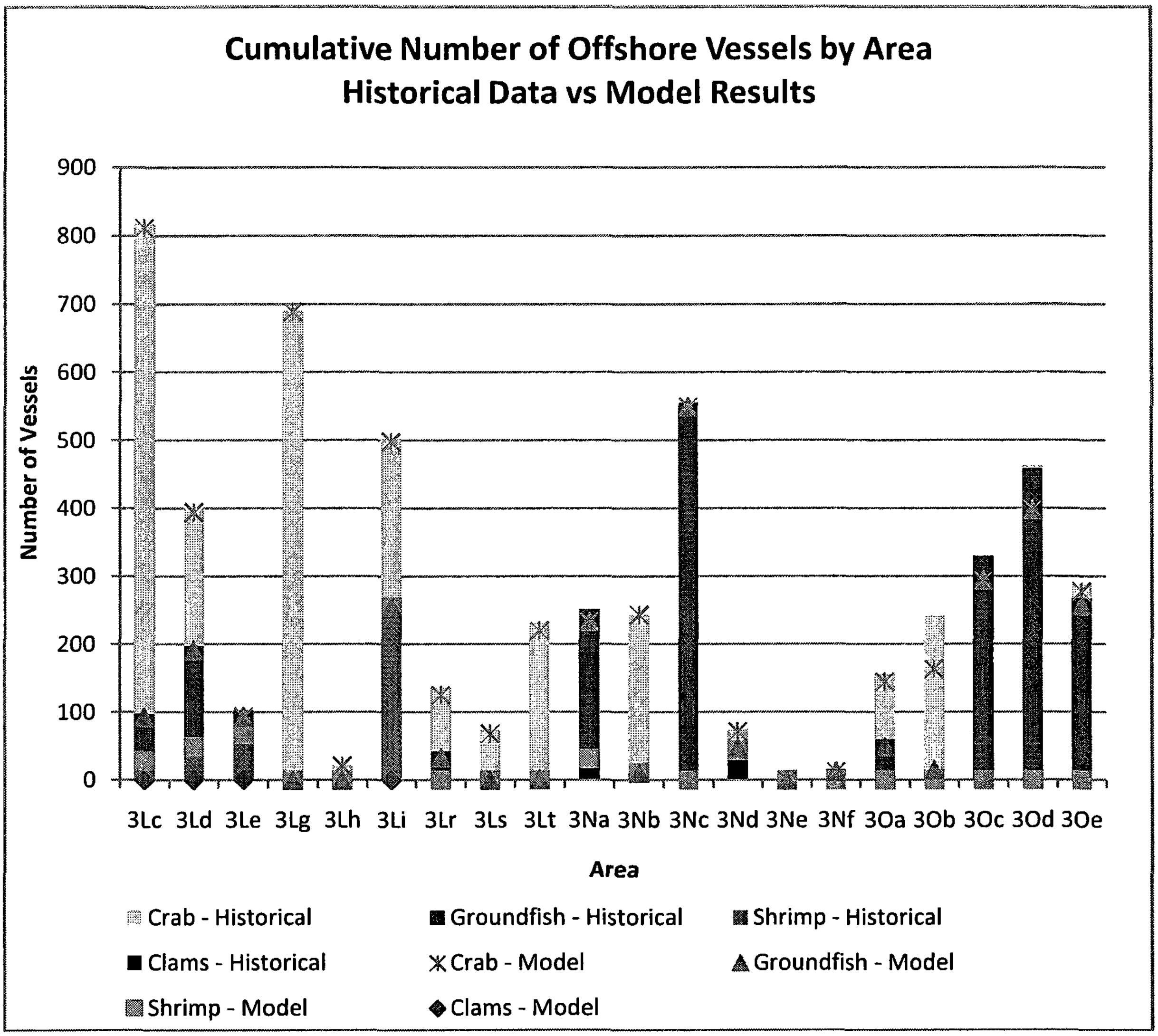

Figure 5.3.8 Cumulative Number of Offshore Vessels by Area - Historical vs Model

5.3.2 Comparison by Value

In this section we compare the revenues of the fishing fleet from historical data with the model output. A detailed analysis by fleet segment is presented for groundfish and a more general analysis is presented for the other model subsets. For all the species and gear included in the study, the model results show a 3.3% (Table 5.3.2) improvement in revenue over historical data in comparing the historical versus the LP model results. Catch weight is limited to historical values; therefore the slight increase is attributed to the allocation of vessels to higher-value locations and time periods.

Table 5.3.1 Historical vs Model Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Historical Data	Model	Difference (%)
Inshore	Gillnet LOA<65'	$3,495,475	$3,540,596	1.3%
	Longline LOA<65'	$75,339	$75,270	-0.1%
	Handline	$611,364	$619,437	1.3%
Offshore	Bottom Otter Trawl LOA<100'	$1,735,636	$1,779,974	2.6%
	Bottom Otter Trawl LOA>100'	$11,687,739	$11,815,614	1.1%
	Gillnet LOA<65'	$2,606,730	$2,708,918	3.9%
	Gillnet LOA>65'	$198,127	$207,277	4.6%
	Longline LOA<65'	$1,232,492	$1,263,880	2.5%
	Longline LOA>65'	$1,636,469	$1,687,993	3.1%

Table 5.3.2 Historical vs Model Values – All Vessels

	Historical Data	Model	Difference (%)
Groundfish	$23,280,384	$23,698,958	1.8%
Crab	$125,138,678	$129,382,308	3.4%
Capelin	$2,541,380	$2,665,087	4.9%
Clams	$9,180,699	$9,926,715	8.1%
Shrimp	$12,372,794	$12,510,511	1.1%
Total	**$172,513,934**	**$178,183,578**	3.3%

5.4 Relaxed Model

In this LP model formulation, the upper bounds on catch by location and time period (week) remain the same for each species and gear type combinations. However, we relax constraints on fleet size upper bounds. For each species and gear type combination, the fleet size upper bound by area and time period is increased to equal the maximum value for all areas and for all time periods, respectively. As a result, we see an overall increase in the number of vessels by period; although the increase is not evenly spread over all periods (see Figure 5.4.1 to

Figure 5.4.3). The general pattern that emerges is an increase in the number of vessels at the peak of the season and leading up to the peak, with the exception of for the numbers of inshore groundfish vessels (Figure 5.4.1) whose numbers are greater than average historical values after the final peak at week 38. The overall increase in value between the average 2000-2005 historical figure and the relaxed model results in a potential gain of 5.1% to the Grand Banks fleet landed performance overall (Table 5.4.2). Comparing "Model" and "Relaxed" Net Operating Incomes results show that relaxing constraints on fleet size have a small impact, less than 2% for both groundfish vessels (Table 5.4.1) and all vessels (Table 5.4.2).

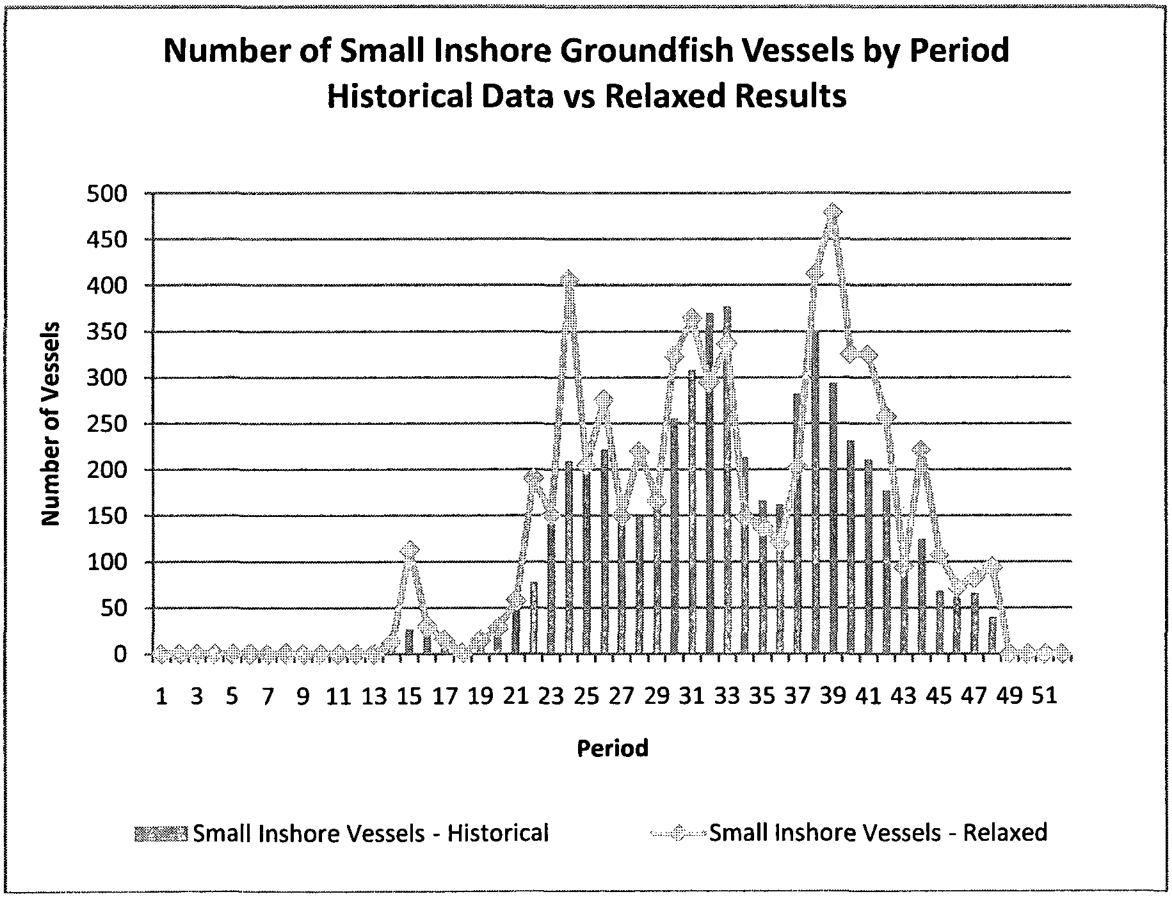

Figure 5.4.1 Number of Inshore Groundfish Vessels by Period – Historical vs Relaxed

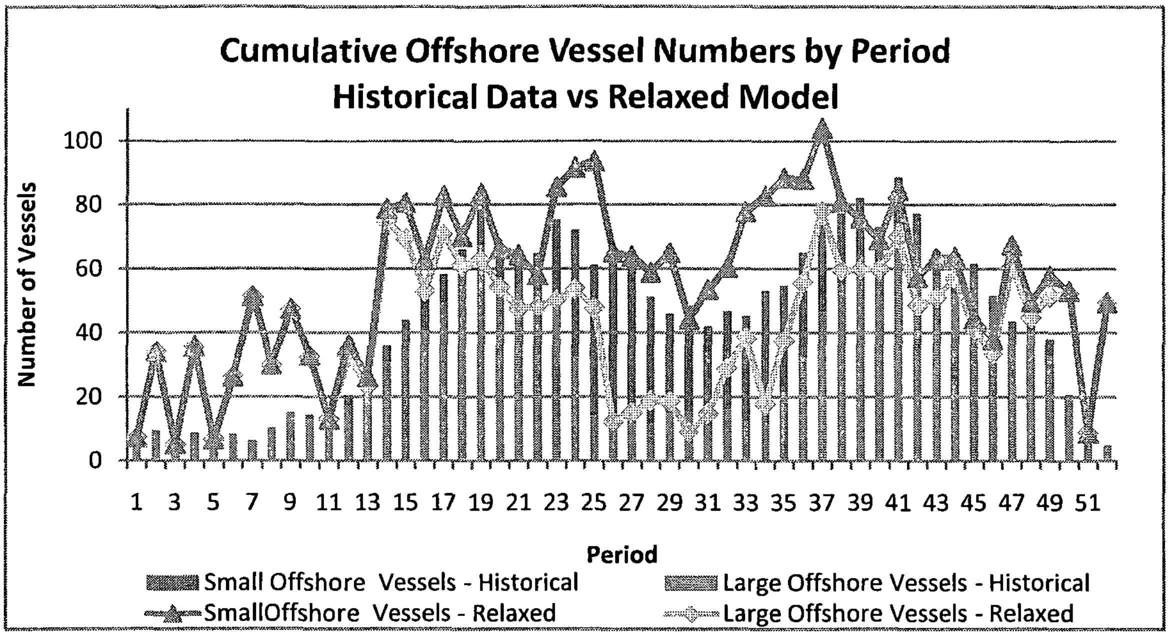

Figure 5.4.2 Cumulative Numbers of Offshore Vessels – Historical vs Relaxed

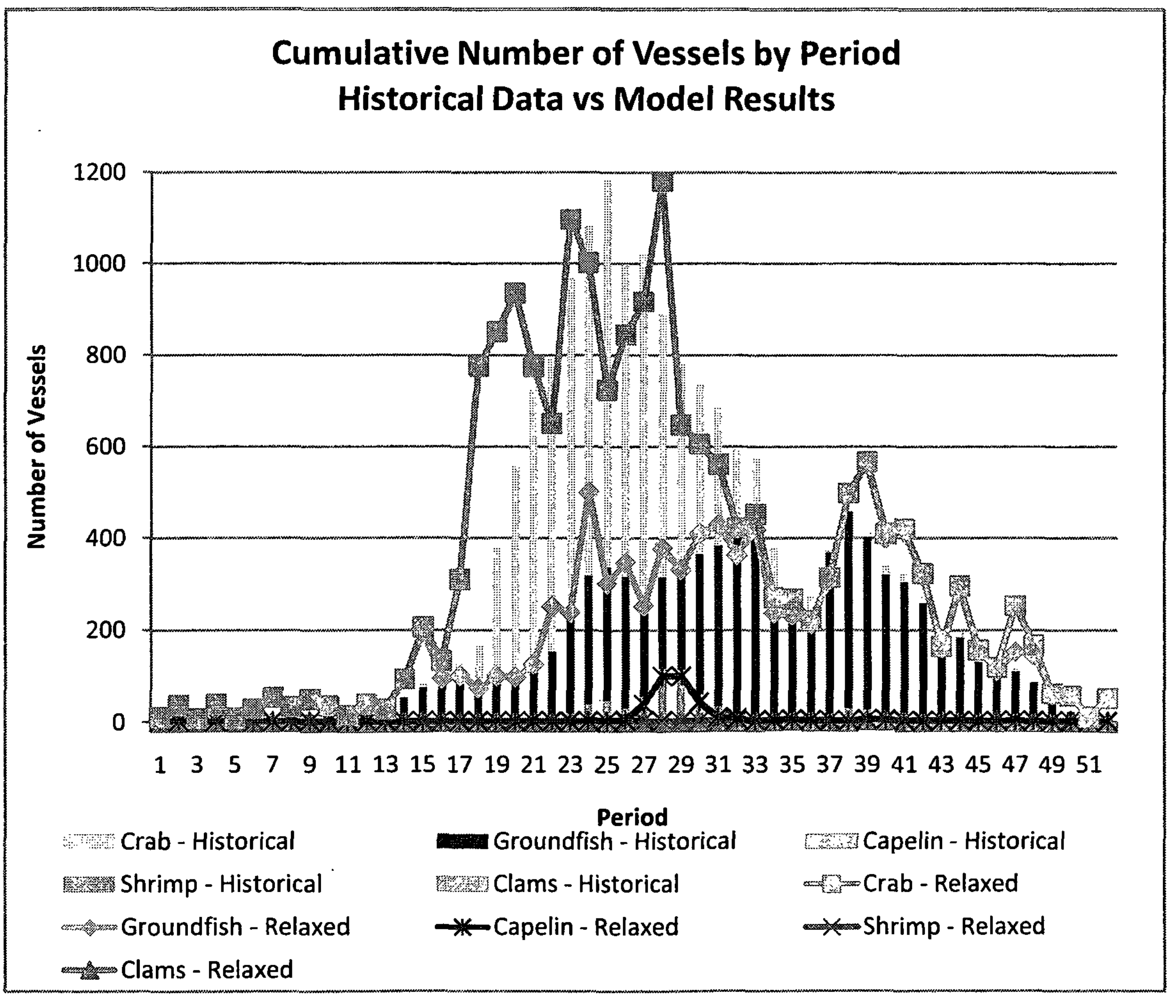

Figure 5.4.3 Cumulative Numbers of Vessels – Historical vs Relaxed

Table 5.4.1 Historical, Model and Relaxed Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Historical (1)	Model (2)	Relaxed (3)	1 vs 2 (%)	2 vs 3 (%)
Inshore	Gillnet LOA<65' (19.8m)	$3,495,475	$3,540,596	$3,588,130	2.7%	1.3%
	Longline LOA<65'	$75,339	$75,270	$75,651	0.4%	0.5%
	Handline	$611,364	$619,437	$636,205	4.1%	2.7%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$1,735,636	$1,779,974	$1,809,829	4.3%	1.7%
	Bottom Otter Trawl LOA>100'	$11,687,739	$11,815,614	$11,876,916	1.6%	0.5%
	Gillnet LOA<65'	$2,606,730	$2,708,918	$2,742,657	5.2%	1.2%
	Gillnet LOA>65'	$198,127	$207,277	$211,591	6.8%	2.1%
	Longline LOA<65'	$1,232,492	$1,263,880	$1,278,084	3.7%	1.1%
	Longline LOA>65'	$1,636,469	$1,687,993	$1,720,436	5.1%	1.9%

Table 5.4.2 Historical, Model and Relaxed Values- All Vessels

	Historical (1)	Model (2)	Relaxed (3)	2 vs 3 (%)	1 vs 3 (%)
Groundfish	$23,280,384	$23,698,958	$23,768,063	0.3%	2.1%
Crab	$125,138,678	$129,382,308	$131,964,477	2.0%	5.5%
Capelin	$2,541,380	$2,665,087	$2,676,663	0.4%	5.3%
Clams	$9,180,699	$9,926,715	$10,090,363	1.6%	9.9%
Shrimp	$12,372,794	$12,510,511	$12,726,978	1.7%	2.9%
Total	**$172,513,934**	**$178,183,578**	**$181,307,631**	1.8%	5.1%

5.5 Net Operating Income

This LP model formulation takes into account operating costs of the Grand Banks fishing fleets and is based on the relaxed version of the model with regards to constraints on fishing limits and vessel deployment. It is also used as a baseline for the scenario analysis performed in section 5.6 below. The cost structure used in implementing net operating income can be found in section 4.8 above. Table 5.5.1 presents an example of the Net Operating Income model inputs and results for crab vessels from 25' (7.6m) to 65' (19.8m) LOA. Our sources for the cost structure are DFO's 2004 Costs and Earnings Survey and a 2007 internal report to DFO (Canada 2007i and Lane 2007).

The fleet operating cost structure is identified separately for each individual fleet in the Grand Banks fleet. Operating costs are comprised of three primary items, namely (1) Labour; (2) Fuel, Oil, and Grease; and (3) Other (including Provisions, Bait, and Ice). These operating cost items are identified as a proportion of total operating costs for the fleet segment. Net Operating Costs are determined from the estimated ratio of Operating Costs to Revenue (Landed Value), as in Table 5.5.1 below for the Crab fleet (25 to 65 foot vessels).]

Table 5.5.1 Operating Cost Structure Example

Gear Type and Vessel LOA	Labour	Fuel, Oil and Grease	Other	Operating Cost to Revenue Ratio
Crab 25' to 65' (19.8m)	*0.81*	*0.08*	*0.11*	*0.59*

In order to arrive at the average weekly operating costs per vessel, we compute the operating cost to revenue ratio for each data point; e.g. the ratio for crab landings by vessels from 25' to 65' LOA in area 3Lc during week 25. The average ratio for all data points is calculated using a weighted average. Catch weight in kg is used for each data point included in the weighted average. We then derive the average weekly operating cost that yields an average cost to revenue ratio equal to the historical value listed in Table 5.5.1. As noted above, operating costs are divided into three categories; (1) Labour; (2) Fuel, Oil and Grease; and (3) Other. This third category includes Provisions, Bait and Ice. Dividing operating costs into these components allows the independent increase of each one for the purpose of scenario (1) Labour; (2) Fuel, Oil and Grease; and (3) Other. This third category includes Provisions, Bait and Ice. Dividing operating costs into these components allows the independent increase

of each one for the purpose of scenario analyses. For example, a 20% increase in labour costs results in a 16.2% operating cost increase for crab vessels between 25' and 65' LOA.

Changes in value from gross to net operating income not only reflect changes in inputs, e.g. labour costs, but they also reflect changes in vessel allocation as performed by the linear programming algorithm. Where feasible, vessels will not be allocated to time period and location combinations that have a negative objective function coefficient, corresponding to the potential incurrence of a net operating loss. The percentage decrease from gross to net operating income (reflecting the importance of the operating costs per fleet) is different for each fleet segment as shown in Table 5.5.2 and Table 5.5.3 below. The latter shows that the average annual (2000-2005) overall loss from Gross to Net Operating Income for all Grand Banks fleets is 50% of Gross Revenue. This table also shows that Crab vessels incur an average decrease in income compared to the entire Grand Banks fleet, whereas groundfish and capelin vessels incur a less than average decrease and clams and shrimp vessels a larger than average decrease. In regards to the groundfish fleet (Table 5.5.2), smaller vessels exhibit a smaller decrease in income than larger vessels. Furthermore, bottom otter trawl vessels exhibit a greater decrease in income compared to gillnet and longline vessels.

Table 5.5.2 Model vs Baseline Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Model	Baseline	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$3,540,596	$2,382,733	-31.8%
	Longline LOA<65'	$75,270	$44,912	-40.4%
	Handline	$619,437	$342,820	-43.9%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$1,779,974	$904,321	-47.9%
	Bottom Otter Trawl LOA>100'	$11,815,614	$5,363,527	-54.1%
	Gillnet LOA<65'	$2,708,918	$1,638,866	-37.1%
	Gillnet LOA>65'	$207,277	$114,062	-42.4%
	Longline LOA<65'	$1,263,880	$972,995	-21.1%
	Longline LOA>65'	$1,687,993	$1,240,718	-24.2%

Table 5.5.3 Model vs Baseline Values – All Vessels

	Model	Baseline	Difference (%)
Groundfish	$23,280,384	$13,004,954	-44.1%
Crab	$125,138,678	$56,972,075	-50.3%
Capelin	$2,541,380	$1,553,046	-38.9%
Clams	$9,180,699	$4,255,161	-53.7%
Shrimp	$12,372,794	$5,164,996	-58.3%
Total	$172,513,934	$80,950,233	-50.0%

Overall numbers of vessels are reduced compared to historical values with the exception of an increase in crab vessels during time periods leading up to the peak (see Figure 5.5.1 below. The decrease in the number of vessels is particularly evident during the last peak of groundfish vessel activity from week 37 to 40.

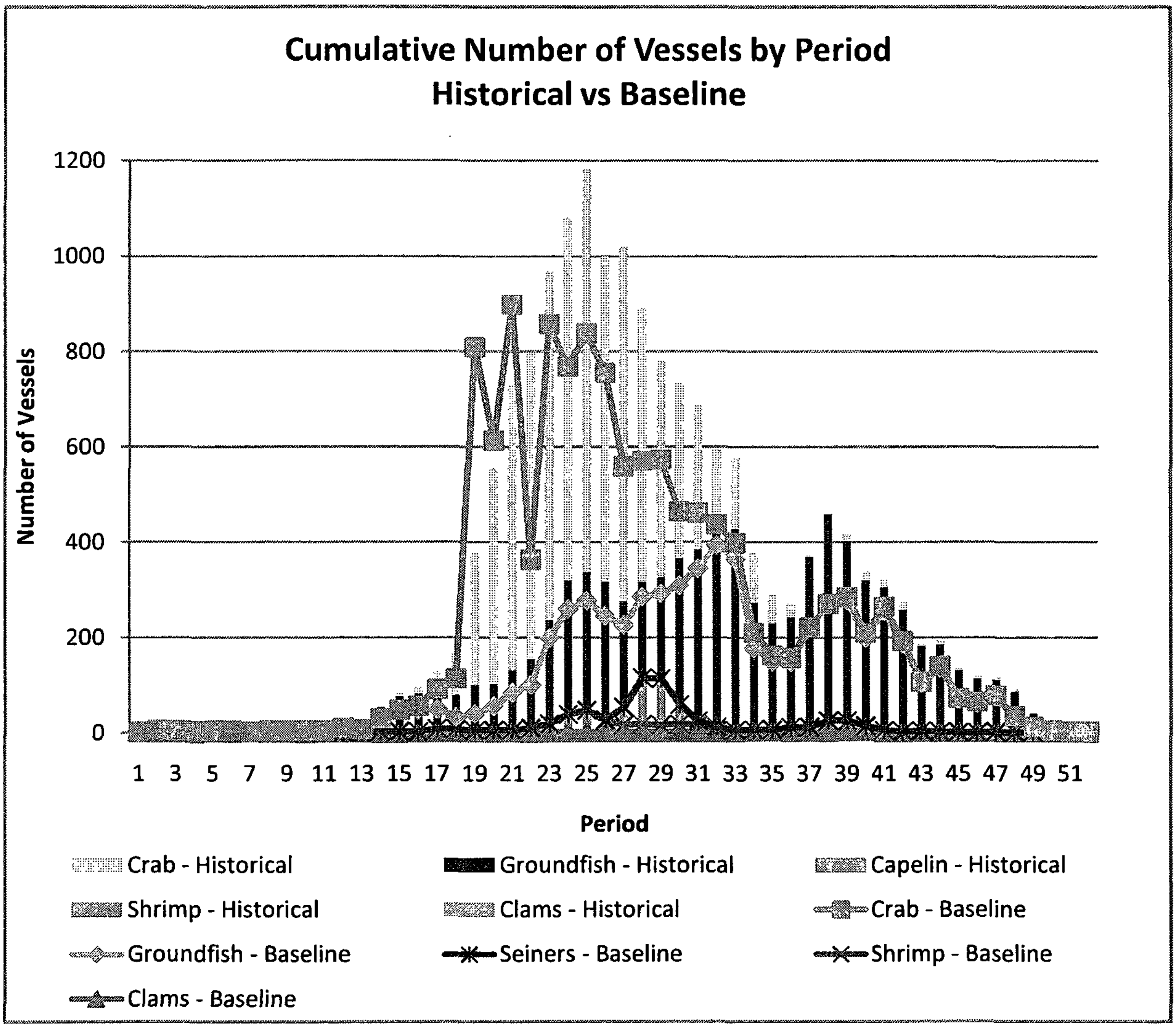

Figure 5.5.1 Cumulative Numbers of Vessels – Historical vs Baseline

5.6 Scenario Analysis

Economic circumstances and resource availability can vary dramatically over time, as experienced by the fishing industry in the past few decades and as discussed in Chapter 1 of this thesis. It is important to take into account such possible developments and examine their impact on the operating income and the configuration of the fishing fleet. The LP model system derived for the Grand Banks fleet component and described and validated above for the current period provides an ideal framework for examining the economic performance of the fleet model under a variety of realistic scenarios. Similarities and differences between the alternative scenarios and their results will be examined to represent a fishing fleet structure that would be resilient and able to adapt to a wide range of possible future circumstances, as has been suggested in the development of the governments' "Ocean to Plate" approach to fisheries renewal. Moreover, this information is very useful to the government as regulator in order to apply matching policy that can aid the fleets in adapting to the changes that they face.

Modifying the parameters of the model and running it under different conditions in the scenario analysis will result in changes in the fleet configuration. Changes in parameters include significant adjustments to operating costs. This change mimics for example the dramatic fuel increase of 2008 that had a huge economic impact on certain fishing gear types, and have led in response to direct government intervention and support, e.g., fuel subsidy programs to fishermen. Changes in market prices are also taken into consideration in the scenario analysis by allowing decreases in the price per kg of landed fish and the impact that such a fall in price would have. This scenario is particularly relevant as consumers hit by the current global economic crisis cut back on luxury items such as lobster, creating a glut in supply and putting downward pressure on prices. (The recent case of falling lobster prices and a glut in inventories at the start of the major lobster fishing season has precipitated major inquiries by the parliament of Canada and the new Minister of Fisheries in response to the crisis this is causing in Atlantic Canada for lobster fishermen (who are seeking price subsidies), and lobster processors (who are seeking market protection).)

The scenarios defined in Table 5.6.1 below are used to illustrate the model's capabilities and uses and to reflect actual changes impacting the commercial fisheries currently, as described above. These scenarios are representative of a wide range of possible analyses that could be undertaking using the LP model framework. Further discussion of scenario analyses are provided in Chapter 6 below

Table 5.6.1 Scenarios

Scenario	Scenario Description	Parameters	Parameter Changes
I	Global rise in Oil & Gas	Fuel	+20%
II	Union Labour Pressures	Labour	+20%
III	Combine costs increases	Fuel and Labour	+20%
•IV	Global Fisheries product	Market Price	-25%
V	Pessimistic Outlook	All of the Above	Same as above
VI	Global Market rebound	Market Price	+25%

5.6.1 Scenario I

This first scenario models a 20% increase in fuels costs. Table 5.6.3 shows that fleets operating fixed gear types are less affected than the mobile gear fleets, e.g., clams and shrimp, harvested solely by mobile gear types using dredges. This fleet shows the largest decline in Net Operating Income versus the Baseline model results, of around 9%. In contrast, the crab fleet uses fixed gear and has less use fuel for fishing. This fleet exhibits only a 1.7% decrease in gross operating income due to the fuel increase. Because crab represents the majority of catches in our area of study, the overall impact of a 20% increase in fuel costs is limited to a 2.8% reduction in net operating income. In the groundfish fleet (Table 5.6.2), the impact is more pronounced on vessels operating bottom otter trawls and gillnet vessels over 65' (19.8m) with a decrease in Net Operating Income estimated at 6.6%..

Table 5.6.2 Baseline vs Scenario I Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario I	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$2,348,807	-1.4%
	Longline LOA<65'	$44,912	$44,047	-1.9%
	Handline	$342,820	$334,623	-2.4%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$861,806	-4.7%
	Bottom Otter Trawl LOA>100'	$5,363,527	$5,007,100	-6.6%
	Gillnet LOA<65'	$1,638,866	$1,618,147	-1.3%
	Gillnet LOA>65'	$114,062	$107,457	-5.8%
	Longline LOA<65'	$972,995	$967,370	-0.6%
	Longline LOA>65'	$1,240,718	$1,211,265	-2.4%
Total	**Groundfish**	**$13,004,954**	**$12,500,623**	**-3.9%**

Table 5.6.3 Baseline vs Scenario I Values – All Vessels

	Baseline	Scenario I	Difference (%)
Groundfish	$13,004,954	$12,500,623	-3.9%
Crab	$62,253,595	$61,220,108	-1.7%
Capelin	$1,553,046	$1,531,603	-1.4%
Clams	$4,255,161	$3,870,266	-9.0%
Shrimp	$5,164,996	$4,721,775	-8.6%
Total	**$86,231,752**	**$83,844,376**	**-2.8%**

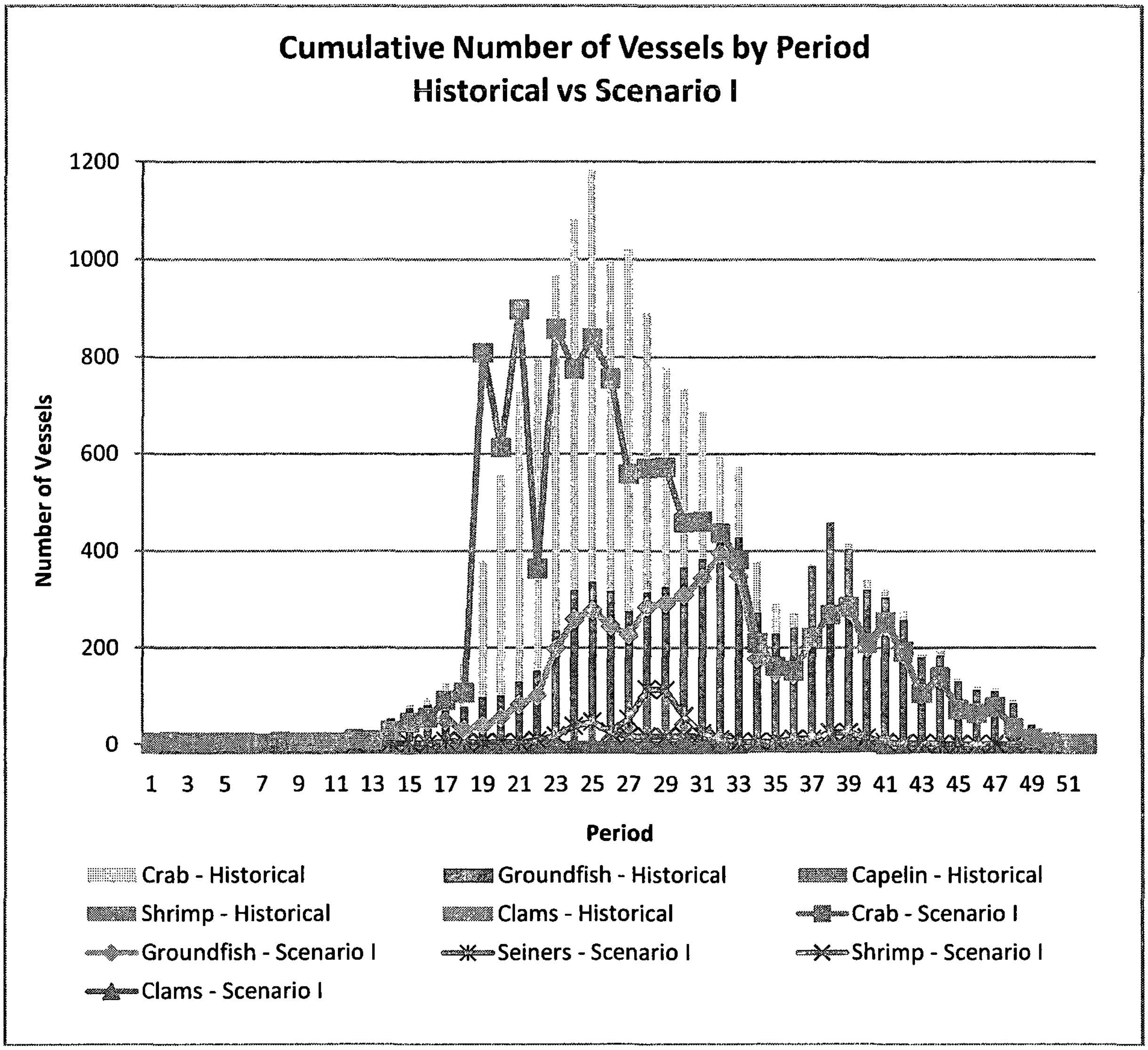

Figure 5.6.1 Cumulative Numbers of Vessels – Historical vs Scenario I

With regard to fleet size, the limited impact of an increase in fuel costs is hardly noticeable and limited to crab vessels when Figure 5.6.1 above is compared with Figure 5.5.1 that corresponds to the baseline scenario.

5.6.2 Scenario II

The second scenario simulates a 20% increase in labour costs. Crab vessels exhibit the largest decrease in maximizing Net Operating Income relative to the baseline case with a 15.5% decrease due to the importance of labour in crab fishing (Table 5.6.5). Shrimp vessels are next with a 14.9% decrease. A 7.9% decrease is estimated for groundfish vessels operating optimally for Net Operating Income. This represents the smallest decrease and is related to the larger scale, automated and reduced labour use in groundfishing on the Grand Banks. A more detailed analysis of the groundfish fleet (Table 5.6.4) shows that labour accounts for a larger share of operating costs for smaller vessels that larger vessels in groundfish fleet. Everything else being equal, an increase in labour costs has a larger effect on Net Operating Income than the same increase in fuel costs.

Table 5.6.4 Baseline vs Scenario II Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario II	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$2,348,807	-7.5%
	Longline LOA<65'	$44,912	$44,047	-10.1%
	Handline	$342,820	$334,623	-12.6%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$861,806	-10.7%
	Bottom Otter Trawl LOA>100'	$5,363,527	$5,007,100	-8.9%
	Gillnet LOA<65'	$1,638,866	$1,618,147	-9.4%
	Gillnet LOA>65'	$114,062	$107,457	-5.5%
	Longline LOA<65'	$972,995	$967,370	-4.3%
	Longline LOA>65'	$1,240,718	$1,211,265	-2.5%
Total	**Groundfish**	**$13,004,954**	**$11,974,913**	**-7.9%**

Table 5.6.5 Baseline vs Scenario II Values – All Vessels

	Baseline	Scenario II	Difference (%)
Groundfish	$13,004,954	$11,974,913	-7.9%
Crab	$62,253,595	$52,594,394	-15.5%
Capelin	$1,553,046	$1,391,576	-10.4%
Clams	$4,255,161	$3,720,597	-12.6%
Shrimp	$5,164,996	$4,395,358	-14.9%
Total	**$86,231,752**	**$74,076,838**	**-14.1%**

According to Figure 5.6.2. the overall decrease in the number of vessels is more visible than in Scenario I for crab vessels; the other fleet sizes remain similar to the baseline scenario. (figure 5.5.1).

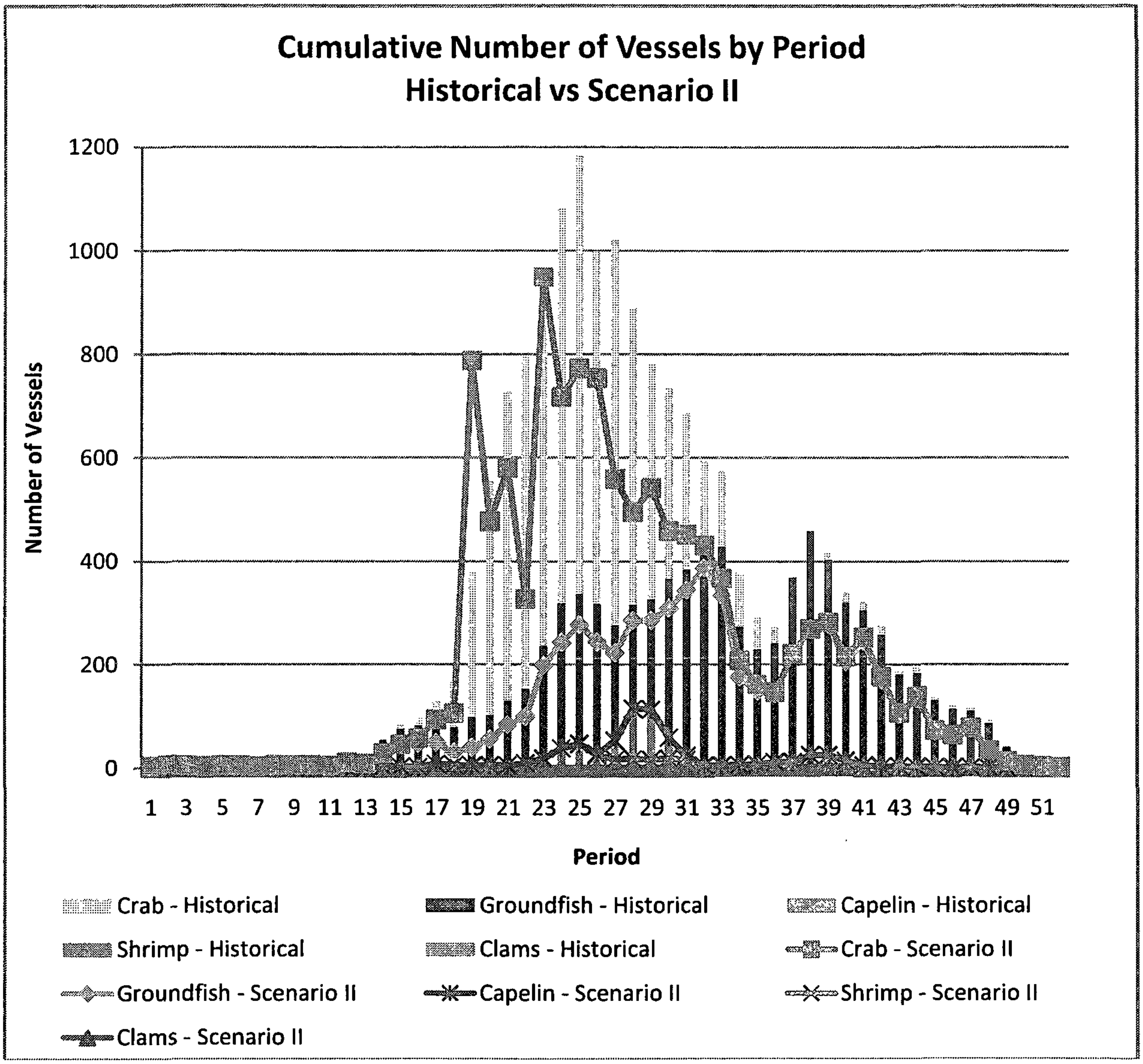

Figure 5.6.2 Cumulative Numbers of Vessels – Historical vs Scenario II

5.6.3 Scenario III

The third scenario combines the 20% increase in labour with the same increase in fuel costs modelled in the first two scenarios. Shrimp and clams vessels show the decrease in Net Operating Income (and highest relative impact on operating costs) whereas Capelin and groundfish vessels are the least affected by the joint increases (Table 5.6.7). In the Groundfish fleet, larger vessels are more sensitive to operating cost increases (Table 5.6.6).

Table 5.6.6 Baseline vs Scenario III Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario III	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$2,182,097	-8.4%
	Longline LOA<65'	$44,912	$39,804	-11.4%
	Handline	$342,820	$294,250	-14.2%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$765,631	-15.3%
	Bottom Otter Trawl LOA>100'	$5,363,527	$4,885,868	-8.9%
	Gillnet LOA<65'	$1,638,866	$1,486,843	-9.3%
	Gillnet LOA>65'	$114,062	$107,806	-5.5%
	Longline LOA<65'	$972,995	$931,913	-4.2%
	Longline LOA>65'	$1,240,718	$1,209,829	-2.5%
Total	**Groundfish**	**$13,004,954**	**$11,904,333**	**-8.5%**

Table 5.6.7 Baseline vs Scenario III Values – All Vessels

	Baseline	Scenario III	Difference (%)
Groundfish	$13,004,954	$11,904,040	-8.5%
Crab	$62,253,595	$51,658,247	-17.0%
Capelin	$1,553,046	$1,370,346	-11.8%
Clams	$4,255,161	$3,351,626	-21.2%
Shrimp	$5,164,996	$3,965,559	-23.2%
Total	**$86,231,752**	**$72,249,819**	**-16.2%**

With regards to fleet size (Figure 5.6.3), fewer vessels are allocated to the crab fleet overall compared to the baseline scenario (Figure 5.5.1). The other fleets experience little visible change in their numbers; the main impact of the increases in costs being reflected in their Net Operating Income decrease.

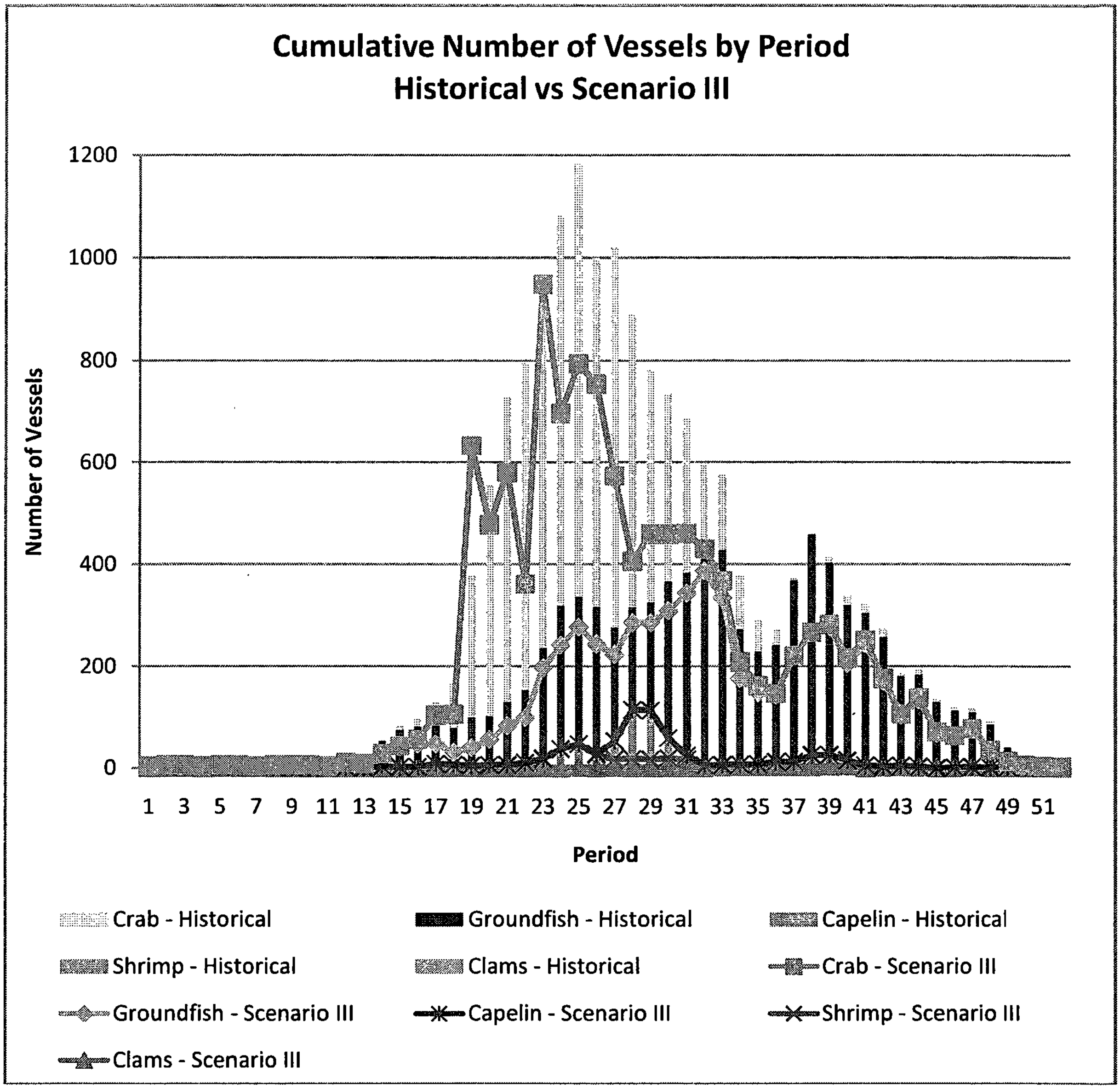

Figure 5.6.3 Cumulative Numbers of Vessels – Historical vs Scenario III

5.6.4 Scenario IV

This scenario models a 25% decrease in price per kg of landed fish. The 42.3% decrease in overall net operating income reflects the large impact of such changes in market prices. Shrimp and clams vessels are affected the most, groundfish and capelin vessels the least, by the price decrease (Table 5.6.9). Vessels equipped with bottom otter trawls exhibit the largest reduction in net operating income of all groundfish vessels (Table 5.6.8).

Table 5.6.8 Baseline vs Scenario IV Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario IV	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$1,506,311	-36.8%
	Longline LOA<65'	$44,912	$26,568	-40.8%
	Handline	$342,820	$188,969	-44.9%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$476,317	-47.3%
	Bottom Otter Trawl LOA>100'	$5,363,527	$2,775,544	-48.3%
	Gillnet LOA<65'	$1,638,866	$971,897	-40.7%
	Gillnet LOA>65'	$114,062	$64,142	-43.8%
	Longline LOA<65'	$972,995	$660,576	-32.1%
	Longline LOA>65'	$1,240,718	$834,964	-32.7%
Total	**Groundfish**	**$13,004,954**	**$7,505,288**	**-42.3%**

Table 5.6.9 Baseline vs Scenario IV Values – All Vessels

	Baseline	Scenario IV	Difference (%)
Groundfish	$13,004,954	$7,505,288	-42.3%
Crab	$62,253,595	$32,481,993	-47.8%
Capelin	$1,553,046	$892,426	-42.5%
Clams	$4,255,161	$1,917,114	-54.9%
Shrimp	$5,164,996	$2,163,455	-58.1%
Total	**$86,231,752**	**$44,960,276**	**-47.9%**

The decrease in Net Operating Income is not only due to the direct impact of lower prices, but also results from a smaller number of vessels being allocated to the crab fleet (Figure 5.6.4). The decrease in the number of crab vessels is clearly noticeable in the period leading up to the peak, but the fleet size remains the same during the peak as in previous scenarios.

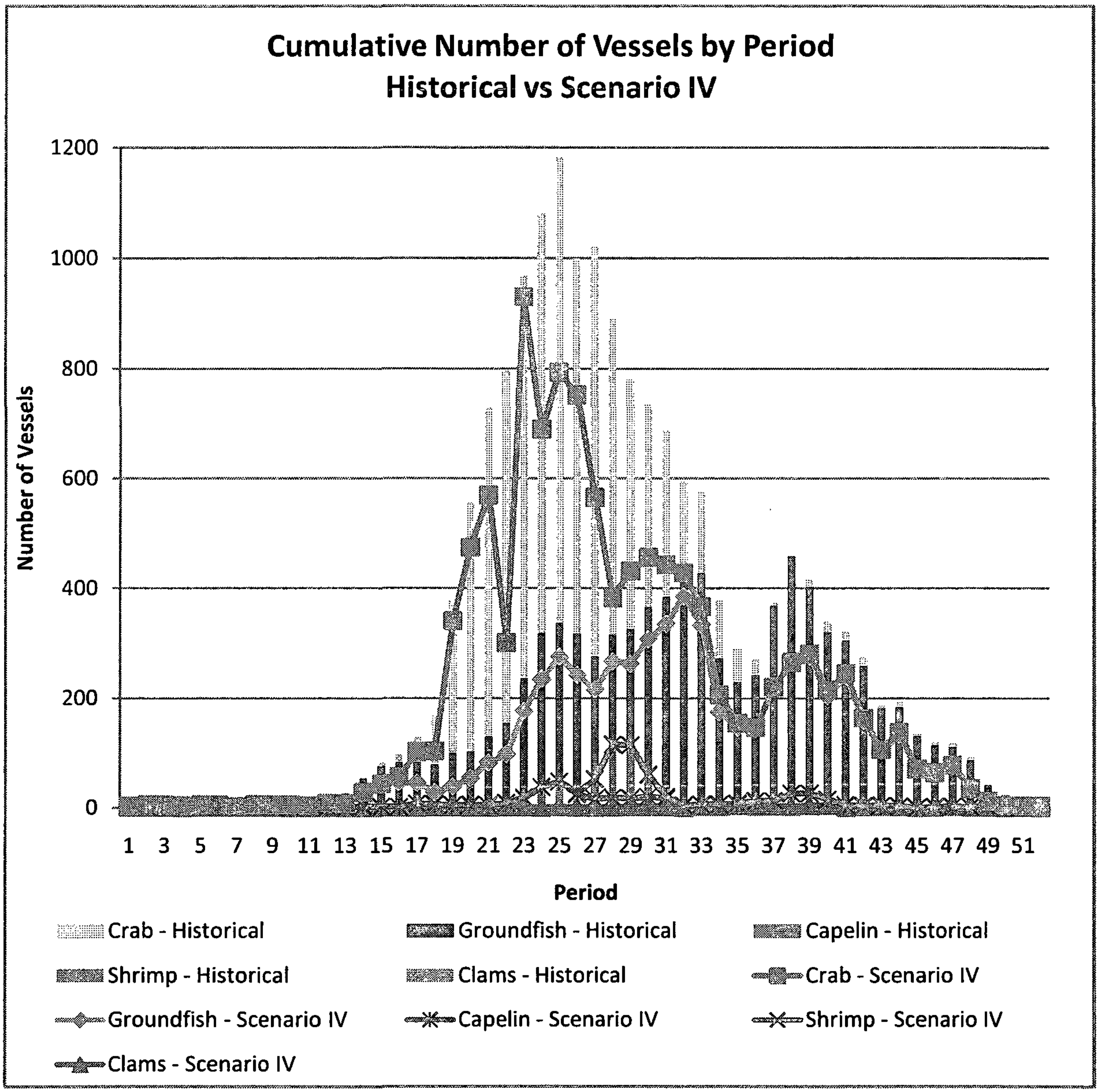

Figure 5.6.4 Cumulative Numbers of Vessels – Historical vs Scenario IV

5.6.5 Scenario V

This scenario is the most pessimistic and combines the increases in costs of Scenarios I-II, with the decrease in fish market value of Scenario IV. As a result, overall LP optimized Net Operating Income for all Grand Bank fleets is reduced by 62.2%. (Table 5.6.11) A comparison with the 47.9% decrease in the previous scenario (Scenario IV – 25% market price drop) shows that changes in market prices have a much larger impact on net operating income relative to comparable changes in operating costs since most of this cumulative change is attributed to the price and revenue decline. Shrimp vessels are the most affected by the combined change. Their net operating income decreases by more than three-quarters. Table 5.6.11 shows that groundfish vessels are the least affected with a nevertheless significant 53.4% decrease in maximized Net Operating Income. Within the groundfish fleet, offshore longliners see a decrease of only 37% whereas Net Operating Income levels to Bottom Otter Trawl vessels decreases by 63%.(Table 5.6.10).

Table 5.6.10 Baseline vs Scenario V Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario V	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$1,310,288	-45.0%
	Longline LOA<65'	$44,912	$21,647	-51.8%
	Handline	$342,820	$140,863	-58.9%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$341,342	-62.3%
	Bottom Otter Trawl LOA>100'	$5,363,527	$1,985,906	-63.0%
	Gillnet LOA<65'	$1,638,866	$808,279	-50.7%
	Gillnet LOA>65'	$114,062	$53,188	-53.4%
	Longline LOA<65'	$972,995	$616,749	-36.6%
	Longline LOA>65'	$1,240,718	$785,374	-36.7%
Total	**Groundfish**	**$13,004,954**	**$6,063,635**	**-53.4%**

Table 5.6.11 Baseline vs Scenario V Values – All Vessels

	Baseline	Scenario V	Difference (%)
Groundfish	$13,004,954	$6,063,635	-53.4%
Crab	$62,253,595	$23,337,670	-62.5%
Capelin	$1,553,046	$725,734	-53.3%
Clams	$4,255,161	$1,282,665	-69.9%
Shrimp	$5,164,996	$1,170,094	-77.3%
Total	**$86,231,752**	**$32,579,799**	**-62.2%**

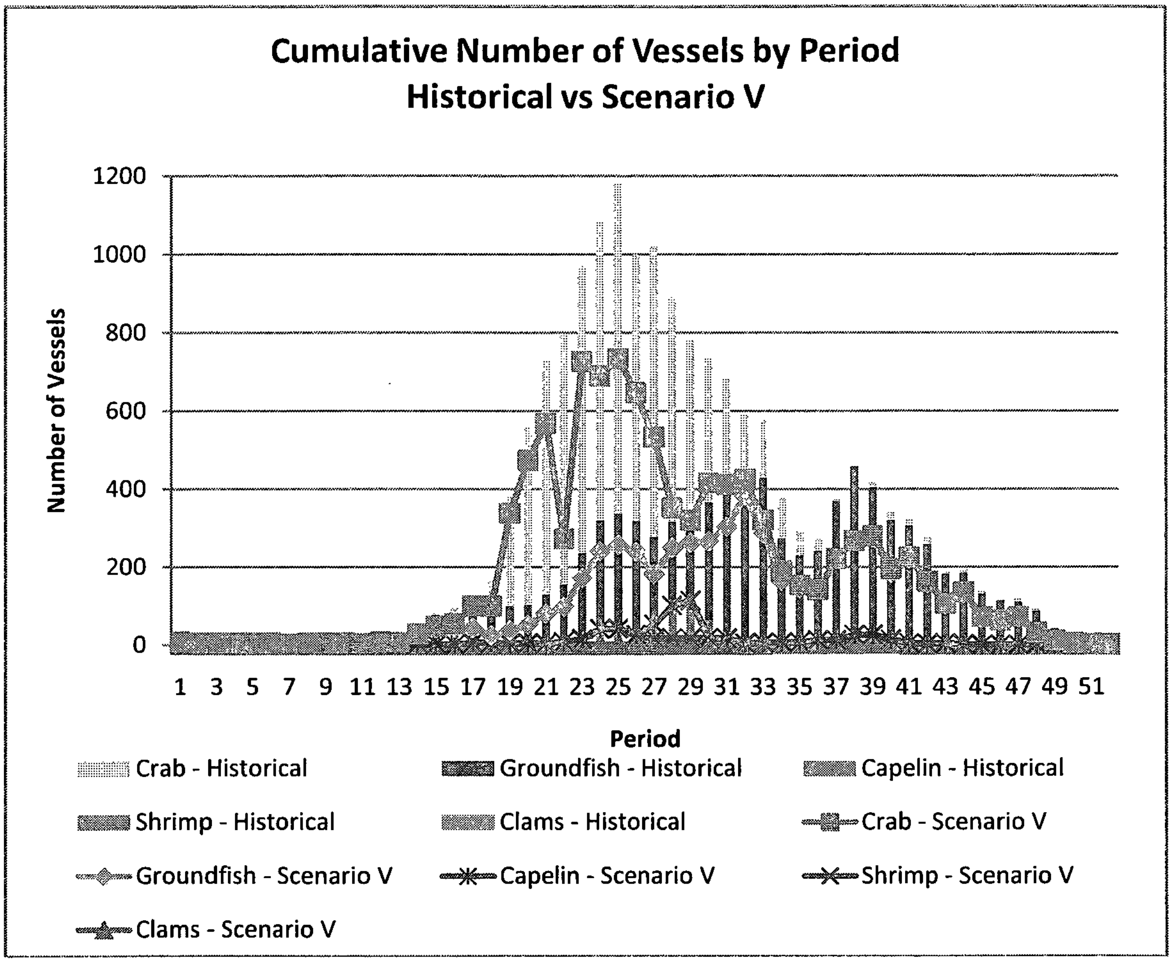

Figure 5.6.5 Cumulative Numbers of Vessels – Historical vs Scenario V

The impact of the changes emulated in this scenario affect all fleets, particularly crab vessels (Figure 5.6.5). Although the changes in the number of vessels for the shrimp, clam and capelin fleet because of their small size relative to the crab and groundfish fleets, a careful examination of Figure 5.6.5 will reveal a visible decline in the size of all fleets.

5.6.6 Scenario VI

This final scenario emulates an improvement in economic conditions resulting in a 25% increase in the price per kg of landed fish. The 51% increase in the Grand Bank fleet's overall level of annual Net Operating Income is significant (Table 5.6.13). Shrimp and crab show the largest increase, capelin and groundfish the smallest. Bottom Otter Trawl vessels benefit the most of all groundfish vessels and longline vessels the least as shown in Table 5.6.12.

Table 5.6.12 Baseline vs Scenario VI Values – Groundfish Vessels

Area	Gear Type and Vessel Size	Baseline	Scenario VI	Difference (%)
Inshore	Gillnet LOA<65' (19.8m)	$2,382,733	$3,250,212	36.4%
	Longline LOA<65'	$44,912	$63,135	40.6%
	Handline	$342,820	$494,324	44.2%
Offshore	Bottom Otter Trawl LOA<100' (30.5m)	$904,321	$1,337,746	47.9%
	Bottom Otter Trawl LOA>100'	$5,363,527	$8,053,970	50.2%
	Gillnet LOA<65'	$1,638,866	$2,315,748	41.3%
	Gillnet LOA>65'	$114,062	$165,410	45.0%
	Longline LOA<65'	$972,995	$1,288,788	32.5%
	Longline LOA>65'	$1,240,718	$1,657,415	33.6%
Total	**Groundfish**	**$13,004,954**	**$18,626,749**	**43.2%**

Table 5.6.13 Baseline vs Scenario VI Values – All Vessels

	Baseline	Scenario VI	Difference (%)
Groundfish	$13,004,954	$18,626,749	43.2%
Crab	$62,253,595	$94,314,232	51.5%
Capelin	$1,553,046	$2,222,422	43.1%
Clams	$4,255,161	$6,735,389	58.3%
Shrimp	$5,164,996	$8,278,161	60.3%
Total	**$86,231,752**	**$130,176,952**	**51.0%**

Overall vessel numbers are larger for all periods compared to historical data, especially in the case of crab vessels during the period leading to the peak Figure 5.6.6, whereas other fleets only show a limited increase in their size.

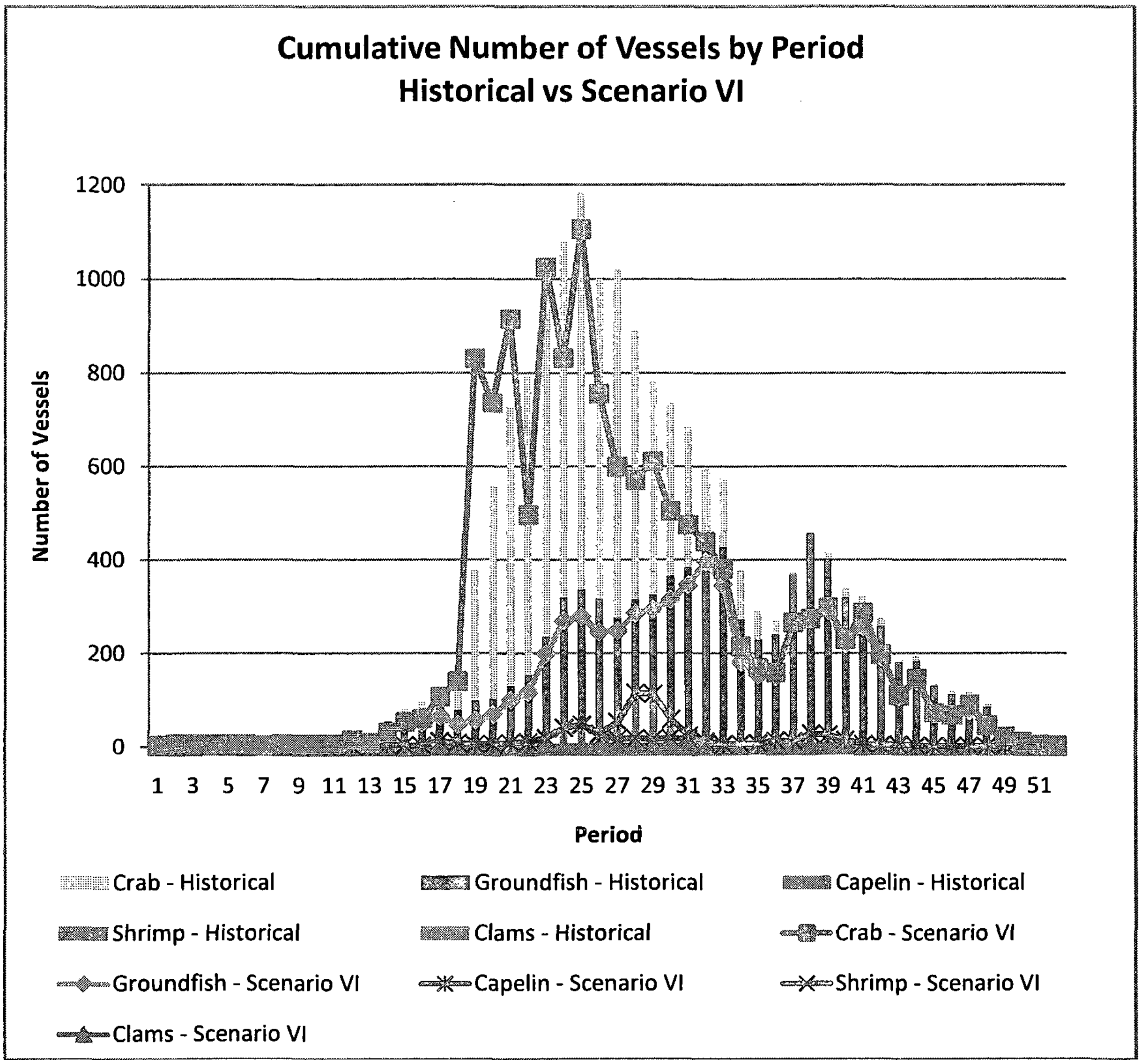

Figure 5.6.6 Cumulative Numbers of Vessels – Historical vs Scenario VI

5.6.7 Scenario Analysis Conclusion

Shrimp and Clams vessels show the largest variations as a result of changes in costs and revenue relative to maximized Net Operating Income for the Grand Banks fleets. They are therefore the most vulnerable to deteriorating economic conditions. Groundfish and Capelin vessels are significantly more resilient although they currently represent a smaller relative component to fleet operations.

Overall, the Crab fleet dominates the Grand Banks fishery in terms of number of vessels, total landed value and geographic coverage and exhibits an average sensitivity to changes in economic conditions. However, Crab vessel numbers are the most visibly affected by the changes in our scenarios. It implies that significant flexibility in the fleet is required in order to adapt to evolving conditions in the form of a reduction in overall vessel activity, be it a reduction in the number of vessels or the decrease in time spent fishing by each vessel. In other words, if there is no reduction in vessel activity during periods of poor economic circumstances, the Crab fleet will experience much larger decreases in Net Operating Income than our LP model shows.

In the Groundfish fleet segment, our analysis indicates that longliners are better positioned to weather the impacts of costs increases and revenue decreases. They would benefit less from an increase in market prices than other fleets, but we can argue that given the repeated crises experienced by the fisheries in the recent past, a fleet that is less affected by downturns is preferable to a fleet that is more vulnerable to such events.

6 Discussion

We began with an historical overview of the Atlantic fisheries and a review of the relevant literature. We focussed on the economic crisis of the early 80's, the resource collapse of the 90's and the recent expressed policy shift to a market-driven approach aimed at achieving economic resilience and prosperity in the fishing industry. This was followed by a discussion of the available means for modelling the fishing fleet configuration and the selection of the Linear Programming model for describing the economic performance of the complex Grand Banks fishing fleets. We presented the model formulation along with its implementation and illustration for the fishery on the capelin species.

The results were highly satisfactory as the LP model results closely matched historical data. On reflection, we would recognize that the existing fleets have incentive and tend to act with respect to economic objectives in the manner in which the fleets are deployed throughput the Grand Banks over the recent time period 2000-2005.

In order to drive the model further to reflect the current position and activity of the fleets, we performed an extensive data analysis resulting in detailed characteristics of the Grand Banks fishing fleet. When selecting the main species and gear types that make up more than 95% of the $140 million total average annual landed values on the Grand Banks, we underlined the fact that snow crab accounts for more than two-thirds of that amount. The large number of records available in the DFO ZIFF database (over 50,000 records per year) allowed for a detailed analysis of the significant species and gear type combinations concerning their time and location of activity. We showed that there is a clear localization of the catch in both time and space and we arrived at a very detailed description of the characteristics of the Grand Banks fisheries by location and by time period for each significant species and gear type combination. High correlation coefficients of year-to-year landed weight by location and time period measured in weeks for the years 2000 to 2005 confirmed the repeated spatial and seasonal pattern of catches and validated the use of 2000-2005 average values to describe the current systems and to drive our average annualized LP model. The data analysis of Chapter 4 concluded with the examination of the operating cost structure of the Grand Banks commercial fishing sector by fleet segment.

The data analysis was followed by the complete implementation of the LP model and its use in the analysis of the impact caused by changes in economic conditions on fleet size and net operating income. We were able to show how each fleet segment's size and net operating income is affected by the parameter changes described in each scenario. The detailed discussion of these results follows.

6.1 Crab and Shrimp Fleet Rationalization

The Crab fleet is by far the largest on the Grand Banks and represents more than two thirds of 2000-2005 total average annual landed values for all species and gear types. Its rapid evolution on the grand Banks over the last decade has provided an alternative for many fishermen affected by the groundfish resource collapse of the early 1990s. Crab is a valuable species for the Grand Banks fishery that has enjoyed high prices and good stock conditions. However, our analysis shows that the crab fleet in its current form is very sensitive to changes in economic conditions and more sensitive to these changes than the traditional groundfish fleet.

We also show that flexibility in the fleet size is required in order to adapt to worsening economic conditions without incurring further decreases in net operating income than that predicted by our model. To a somewhat lesser extent, the burgeoning shrimp fishery of the 1990s has also provided an additional source of income for fishermen displaced from the groundfish fishery. Our scenario analysis results show that the shrimp fishery is even more sensitive to changes in economic conditions.

Consequently, this modelling information suggests that both crab and shrimp fleets would benefit from a process of self-rationalization to reduce their fleet size and increase their resilience, particularly in the case of shrimp. The same conclusions are reached in *Canada – Newfoundland Fishing Industry Renewal* (Canada 2006b) where the need to reduce fleet sizes for vessels under 65' (19.8m) LOA that make up the bulk of the snow-crab and shrimp fleets is a priority in implementing the "Oceans to Plate" (OTP) approach.

6.2 Capelin and "Clam" Fleet Sensitivity

Capelin harvesting is concentrated over a period of a few weeks and represents a relatively small portion of total landed value of the Grand Banks fleet as a whole. In this analysis, the "clam" fishery in our scenario analysis includes cockles and scallops. All three are harvested by dredge although clams account for three-quarters of average landed value. Clams and cockles are mainly prosecuted by two large 200' (61m) LOA vessels operating year-round whereas scallops are harvested by a fleet of fewer than ten vessels between 35' (10.7m) and 65' (19.8m) LOA. Nevertheless, dredge average annual catches account for close to $10 million. Scenario analysis results show that the clam fishery is the most sensitive to cost and market prices parameter changes.

6.3 The Groundfish Fleet and the Case of American Plaice

The groundfish fleet is the second largest after crab and shows the least variation as a result of parameter changes in our scenario analysis. Over 2000-2005, average annual landed values reveal that yellowtail flounder is the dominant species, followed by cod, Greenland halibut, redfish, monkfish, Atlantic halibut, lumpfish and American plaice. The overall picture is that groundfish stocks have not rebounded, except for yellowtail flounder and Greenland Halibut (Rose 2007). The case of American plaice is worth mentioning. Fishing on American plaice is currently under moratorium, yet there is a NAFO allowance for a "directed bycatch" of "1 250 kg or 5% of the total catch (by weight) of all species caught in any single fishing set" (NAFO 2004 in Shelton 2005). Shelton notes that "...when the by-catch species is economically equal or greater in value than the target species, an incentive exists to maximize or exceed the by-catch limit". Plaice is a highly sought after species and our calculations show that its landed price is on average equal to the main target species, yellowtail flounder. This provides an incentive to maximize plaice catches, hindering its stock's recovery. American plaice is only captured by bottom otter trawl.

6.4 Alternative Groundfish Catch Methods

We continue our discussion with the impact of different catch methods. Comparing average landed price per kg of fish according to the gear type used to harvest it reveals higher prices for longline than gillnet and Bottom Otter Trawl. This can be explained by the impact of the method of capture on the quality of the fish whereby longline passive gear (i.e., fish must swim onto the gear) generally result in better quality fish that fetches higher prices from buyers.

As consumers become increasingly concerned about the environmental impact of their purchase, negative externalities such as bycatch and seafloor damage are gaining more importance in the assessment of capture methods. Longline is generally advocated as a preferable alternative catch method to Bottom Otter Trawl and gillnet by seafood buying guides produced by environmental organizations. The main issue with gillnet is the significant amount of bycatch and the lower quality of the fish harvested. Bycatch is also an issue with bottom otter trawl, but so is the potential seafloor damage, especially when the same area is intensely trawled. Longline use can also result in bycatch, particularly when the line is set. This recommendation of longline use for groundfish harvesting is consistent with OTP goals of extracting greater value from resources in a sustainable manner.
With regard to the impact of gear types used to capture other species, dredging causes significant short-term disturbance of the seabed with potentially long lasting consequences (Gilkinson et al, 2003). The impact of fixed and passive gear used to capture crab and lobster (stationary pots) is very limited, and so is the impact of gear types used to catch capelin, although the ecosystem impact of capelin removal is significant as it is a common prey species for many other fish stocks, e.g., it is the main prey of cod.

7 Conclusions and Recommendations

This chapter presents brief conclusions and recommendations for further research related to the current thesis work. Section headings describe the nature of these comments below.

7.1 Research objectives

1) Derive a model of the Grand Banks commercial fishing fleet for the recent period.

In Chapter 2 we survey modelling and optimization methods that are applicable to fishing fleet configuration modelling, followed by the LP model formulation in Chapter 3.

2) Provide a detailed characterization of the Grand Banks fishing fleet through an extensive analysis of historical data and use those results as inputs to a quantitative, value-based model of the fishery.

In Chapter 4, data corresponding to significant species and gear types representative of the Grand Banks fishing fleet are selected and analyzed extensively for their dynamic with respect to catch weight and landed value by time period and location. The full implementation of the model defined in Chapter 3 is performed in Chapter 5 based on the results of the data analysis from Chapter 4.

3) Provide a mechanism for the analysis of alternative scenarios for costs, values, and fishing resources and their impacts on the economic viability and fleet configurations for the Grand Banks commercial fishing fleet.

Chapter 5 presents the scenario analysis emulating changes in economic conditions and their impact on the Net Operating Income and number of vessels of each Grand Banks commercial fishing fleet segment. The conclusions regarding the implications of the results presented in Chapter 5 are discussed in Chapter 6 and include alternative fleet configurations.

7.2 Issues in Data Management

A significant portion of the thesis work was dedicated to data management and analysis. The large number of records available, while providing an excellent source of data, proved to be challenging to analyze. For example, deriving the necessary data to graph average annual catches by area for the years 2000 to 2005 for each significant species and gear type combination required 700 values for each year. Because of the large size of the database involved, the spreadsheet program could take several minutes to compute all the values and give the results.

Issues of stability in the spreadsheet program further complicated the thesis research task. Over the course of this research, the spreadsheet's error reporting agent recorded 93 crashes. Online forums proved to be far more useful than the help file provided with the spreadsheet when looking for information regarding built-in formulas, shortcuts, formula building and unexpected behaviour.

7.3 LP Model Sensitivity and Use

In our research we use Linear Programming (LP) combined with scenario analysis to achieve a dynamic response to changes in inputs. The response is dynamic because not only does the fleet operating income vary with changes in inputs, but the vessel allocation also changes. As such, a change in one or more of the input parameters results in a change in net operating income due to two factors. The first is the direct impact of the change on objective function coefficients, hence on the value of the objective function. The second is the indirect impact of changes in vessel allocation as a result of changes in objective function coefficients. For example the time (week) and location (NAFO subdivision) of operation that previously resulted in an operating loss may turn into an operating profit as a result of an increase in market prices. As a result, the algorithm solving the LP model allocates vessels to that time and location provided it maximizes the objective function and meets the constraints, further compounding the direct effect of the increase in market prices on the objective function value.

Conversely, a decrease in price may change some of the objective function coefficient from positive to negative and further reducing the objective function value beyond the decrease caused by the price change.

Our model is an excellent tool for policy makers, industry participants and other researchers with interest on the Grand Bank fisheries. It can be used to examine the impact of a wide range of potential changes. For example, a policy analyst may use it to simulate the effects of Total Allowable Catch (TAC) changes on the economic performance of a fleet. A union researcher could also use it to examine the impact of introducing minimum prices paid by processors to its members in the harvesting sector for the fish, or a change in prices when such agreements are already in place. The industry can also make use of it to examine potential changes, such as the effect of an increase in efficiency on the profitability of the fleet, or evaluating the impact of gear type selection.

Finally, we recognize that the proposed modelling methods and analysis can be expanded and improved. The quality of the data used to drive the model derived from the ZIFF database is excellent. However, the estimation of operating costs can be improved. The source used to derive an estimation of the cost structure for vessels over 65' (19.8m) LOA groups all vessels over 100' (30.5m) LOA in one category, and vessels between 65' and 100' are grouped into two categories, fixed and mobile gear. A better estimation of the cost structure for each vessel category identified in our model would require a comprehensive survey of the Grand Banks fishery, which is beyond the scope of this research. However, the model could be improved by refining vessel categories. For example, the current category of crab vessels between 25' (7.6m) LOA and 65' could be divided into two categories, one with vessels between 25' and 35' LOA and the other from 35' to 65' LOA. A comprehensive survey could yield distinct cost structures for each category. Our choice of number of categories stems from What's Best Professional's limitations on the number of adjustable variables and constraints. For example, our offshore groundfish model subset contains 6,968 adjustable decision variables and 3,180 constraints. The limit on the number of adjustable variables and the number of constraints of 8,000 and 4,000, respectively, does not permit further splitting of current vessel categories into smaller groups. The total number of adjustable variables and constraints of all model subsets add up to 12,922 and 4,698, respectively. It must be noted that the largest model subset did not take more than 1 second of processor time to solve on a personal computer equipped with an Intel® Core 2 Duo 1.83 GHz Processor (T5600) processor.

In our model, catch is limited by gear type and vessel Length Overall (LOA), i.e., we set the maximum catch allowed by gear type and by vessel class equal to average historical levels. The model could be modified to allow the allocation of catch across gear types. A maximum catch could be allowed by species, and the model would allocate catch across gear types and vessel class.

7.4 Alternative Model Applications

Our model is useful for simulations of changes in economic conditions and their impact on the fleet size and operating income. However, the Grand Banks fishing industry also has a significant impact on the social, biological and cultural environments of Newfoundland and Labrador (NL). Our model can be used as part of a larger, multi-criteria decision-making tool that would encompass all of the aspects mentioned above. This is particularly relevant in NL where the fisheries have often been used, albeit implicitly, as an employer of last resort and are also an integral part of the cultural fabric of NL. For example, the analysis tool described above could be used to examine the socio-economic and environmental impact of government policy such as current Employment Insurance eligibility rules for self-employed fishermen.

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Appendix A Data and Analysis

In this appendix, the extensive dataset for the Grand Banks fishery is analysed. The appendix presents the analytical approach and its results.The goal of the data analysis is twofold; first, we characterize the dynamics of the Grand Banks fishing fleet, and second, the results of the data analysis is used to drive the fishing fleet configuration liner programming model formulation and data needs as presented in Chapter 3

The first part of this appendix details the source of the raw data on the Grand Banks fishery, and identifies the steps required to import the raw data into a spreadsheet in order to enable the analysis. The second part presents the data analysis, the results obtained and the justification for the use of these results to develop the fleet configuration model.

Data

A.1 Data source

The data used in the analysis are derived from historical data available from DFO's Zonal Interface Format Files (ZIFF) for the years 1995 to 2005. Each file contains all the records from reported individual commercial fishing vessel landings in NAFO Divisions 3L, 3N and 3O for one calendar year (Canada 2006a).

A single record contains the fields listed in Table A.1.1. Each field is width-delimited and is either alphanumeric or floating point, indicated respectively by A and FP in the table's fourth column. The last column in the table specifies the field width and the position of the radix point in the case of a floating point field. The first number is the field width and the number after the decimal point is the position of the radix point. When that second digit is zero, the radix point is assumed to be integer. For example 5.2 represents a field width of five with the radix point in the third position from the right. The raw data from each ZIFF is imported into a spreadsheet document to perform the manipulation and analysis of the data.

Table A.1.1 ZIFF Fields

Item	Name	Description	Value format	Field Width and Radix Point
1	cfva	Commercial Fishing Vessel Number	A	7
2	grosston	Gross Tonnage	FP	5.0
3	tclass	Gross Tonnage Class	FP	1.0
4	loa	Length Overall (in Feet)	FP	3.0
5	lclass	Length Class	FP	1.0
6	brakehp	Brake Horsepower	FP	5.0
7	bclass	Brake Horsepower Class	FP	1.0
8	tripno	Trip Number	FP	4.0
9	dateland	Date of Landing	FP	8.0
10	unitarea	NAFO Unit Area (See Figure A.12.2)	A	5
11	gearcode	Gear Code	FP	2.0
12	gclass	Gear Class	FP	1.0
13	species	Species	FP	3.0
14	value	Landed Value	FP	10.2
15	weight	Landed Weight	FP	10.0
16	efflag	Effort Flag	A	1
17	daysfish	Days Fished	FP	5.2
18	hoursfish	Hours Fished	FP	5.1
19	amtgear	Amount of Gear	FP	4.0
20	ctchdate	Catch Date	FP	8.0
21	lat	Latitude	FP	12.8
22	long	Longitude	FP	12.8
23	region	Region	A	1
24	year	Year	FP	4.0
25	month	Month	FP	2.0

A.2 Raw Data Manipulation

Each line of text in every ZIFF corresponds to one record. By specifying the field width of each record, as per the format table (above) it is possible to import the data into a spreadsheet. Each row of the spreadsheet corresponds to a record and each column corresponds to a particular field in that record. Due to the large number of records for certain years, it is necessary to split the raw data into two separate files, otherwise they do not fit in their entirety on a single Microsoft Excel spreadsheet.Table A.2.1below indicates the total number of records per year, i.e. in each ZIFF in this analysis. Files totalling more than 65,536 records (the Excel row size import limit) are split and imported in two separate Excel spreadsheets. Despite the data management issues, the large volume of available data records contained in the ZIFFs makes these records suitable for creating a representative model of the Grand Banks fishing fleet configuration.Table A.2.1presents the annual records of the Grand Banks fishing fleet for 1995 to 2005.

The goal of the data analysis is to examine the detailed dynamics of the commercial fisheries on the Grand Banks.

Table A.2.1 Number of records by year

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Number of Records	49667	69284	70750	65501	62535	72565	81125	93187	90837	79361	91709

A.3 Data Filtering

The large number of records available for each year necessitates the filtering out of data by retaining only what is significant for the purpose of this study. This is achieved by selecting the main species that are prosecuted in the area of study and the gear types used for their capture.

A.3.1 Species Selection

The first step in this process is to rank the species. The indicator used for the comparison is the cumulative total landed value which is computed for each species for the years 1995 to 2005. Following is a set of tables showing the twenty topmost species by landed value for each year.

Table A.3.1 Twenty Topmost Species by Total Landed Values 1995

Year	1995	
Species	Landed value	Percentage of total
Snow Crab	$74,881,660	67.52%
Stimpsons Surf Clams	$15,124,321	13.64%
Icelandic Scallops	$9,768,187	8.81%
Lobster	$1,824,720	1.65%
Lumpfish Roe	$1,303,150	1.17%
Swordfish	$1,031,307	0.93%
Skate	$944,819	0.85%
Clams, Mantels & Body Meat	$879,409	0.79%
Porbeagle Shark	$785,037	0.71%
Greenland Halibut	$604,614	0.55%
Atlantic Halibut	$591,887	0.53%
Winter Flounder	$409,334	0.37%
White Hake	$326,380	0.29%
Cod	$308,802	0.28%
Herring	$293,015	0.26%
Bluefin Tuna	$292,106	0.26%
Molluscs, unspecified	$215,686	0.19%
Spider-Toad Crab	$143,017	0.13%
Monkfish	$142,068	0.13%
Groundfish Heads	$118,093	0.11%

Table A.3.2 Twenty Topmost Species by Total Landed Values 1996

Year	1996	
Species	Landed value	Percentage of total
Northern Shrimp	$42,929,531	51.49%
Icelandic Scallops	$14,764,655	17.71%
Stimpsons Surf Clams	$6,016,342	7.22%
Capelin	$2,904,300	3.48%
Greenland Halibut	$2,261,752	2.71%
Redfish	$2,032,233	2.44%
Swordfish	$1,709,711	2.05%
Lobster	$1,635,762	1.96%
Bluefin Tuna	$1,579,549	1.89%
Lumpfish Roe	$1,477,793	1.77%
Ilex Squid	$1,234,808	1.48%
Atlantic Halibut	$691,780	0.83%
Quahaugs, Clams	$489,787	0.59%
Skate	$463,220	0.56%
Sea Urchins	$376,467	0.45%
Cod	$363,082	0.44%
Porbeagle Shark	$317,502	0.38%
Herring	$298,762	0.36%
Monkfish	$226,223	0.27%
White Hake	$219,250	0.26%

Table A.3.3 Twenty Topmost Species by Total Landed Values 1997

Year	1997	
Species	Landed value	Percentage of total
Northern Shrimp	$43,488,005	56.73%
Icelandic Scallops	$6,384,624	8.33%
Stimpsons Surf Clams	$6,029,082	7.86%
Beater Harper Seals Skins	$2,282,974	2.98%
Ilex Squid	$2,137,226	2.79%
Swordfish	$1,611,095	2.10%
Capelin	$1,508,391	1.97%
Lobster	$1,465,839	1.91%
Atlantic Halibut	$1,254,578	1.64%
Redfish	$1,221,263	1.59%
Greenland Halibut	$1,139,242	1.49%
Lumpfish Roe	$964,578	1.26%
Skate	$724,832	0.95%
Cod	$709,751	0.93%
Sea Urchins	$594,649	0.78%
Porbeagle Shark	$587,344	0.77%
Quahaugs, Clams	$479,298	0.63%
Bluefin Tuna	$459,054	0.60%
Herring	$436,366	0.57%
Seal Meat	$380,278	0.50%

Table A.3.4 Twenty Topmost Species by Total Landed Values 1998

Year	1998	
Species	Landed value	Percentage of total
Northern Shrimp	$46,607,851	61.84%
Redfish	$4,920,360	6.53%
Capelin	$4,478,694	5.94%
Cod	$3,909,142	5.19%
Yellowtail Flounder	$3,025,893	4.01%
Icelandic Scallops	$2,073,502	2.75%
Lobster	$1,381,397	1.83%
Swordfish	$1,245,703	1.65%
Greenland Halibut	$1,094,690	1.45%
Atlantic Halibut	$1,027,125	1.36%
Stimpsons Surf Clams	$769,366	1.02%
Sea Urchins	$755,843	1.00%
Bluefin Tuna	$449,050	0.60%
Beater Harper Seals Skins	$438,877	0.58%
Monkfish	$336,469	0.45%
Porbeagle Shark	$323,331	0.43%
Herring	$287,373	0.38%
Skate	$270,032	0.36%
Lumpfish Roe	$233,717	0.31%
Ilex Squid	$193,405	0.26%

Table A.3.5 Twenty Topmost Species by Total Landed Values 1999

Year	1999	
Species	Landed value	Percentage of total
Snow Crab	$111,894,502	80.00%
Cod	$7,343,855	5.25%
Yellowtail Flounder	$4,405,653	3.15%
Swordfish	$2,380,604	1.70%
Capelin	$1,830,935	1.31%
Lobster	$1,629,426	1.16%
Redfish	$1,378,108	0.99%
Stimpsons Surf Clams	$1,164,688	0.83%
Quahaugs, Clams	$960,472	0.69%
Lumpfish Roe	$932,765	0.67%
Greenland Halibut	$928,184	0.66%
Sea Urchins	$840,099	0.60%
Atlantic Halibut	$813,762	0.58%
Bigeye Tuna	$403,209	0.29%
Northern Shrimp	$344,442	0.25%
White Hake	$323,972	0.23%
Skate	$319,258	0.23%
American Plaice	$261,814	0.19%
Beater Harper Seals Skins	$233,344	0.17%
Herring	$232,099	0.17%

Table A.3.6 Twenty Topmost Species by Total Landed Values 2000

Year	2000	
Species	Landed value	Percentage of total
Snow Crab	$129,417,394	76.60%
Yellowtail Flounder	$7,673,445	4.54%
Northern Shrimp	$7,382,674	4.37%
Cod	$5,184,062	3.07%
Greenland Halibut	$3,325,562	1.97%
Stimpsons Surf Clams	$2,901,499	1.72%
Capelin	$2,037,026	1.21%
Lobster	$1,440,791	0.85%
Bluefin Tuna	$1,367,435	0.81%
Atlantic Halibut	$1,172,981	0.69%
Swordfish	$1,145,527	0.68%
Sea Urchins	$944,393	0.56%
Redfish	$877,914	0.52%
Lumpfish Roe	$755,857	0.45%
American Plaice	$499,698	0.30%
Icelandic Scallops	$490,666	0.29%
White Hake	$294,310	0.17%
Porbeagle Shark	$265,498	0.16%
Winter Flounder	$202,501	0.12%
Bigeye Tuna	$179,103	0.11%

Table A.3.7 Twenty Topmost Species by Total Landed Values 2001

Year	2001	
Species	Landed value	Percentage of total
Snow Crab	$108,701,168	67.60%
Yellowtail Flounder	$9,889,917	6.15%
Northern Shrimp	$9,635,235	5.99%
Stimpsons Surf Clams	$6,849,822	4.26%
Cod	$5,616,735	3.49%
Redfish	$3,173,501	1.97%
Greenland Halibut	$2,880,193	1.79%
Capelin	$2,004,578	1.25%
Atlantic Halibut	$1,671,699	1.04%
Lobster	$1,499,628	0.93%
Swordfish	$1,427,130	0.89%
American Plaice	$1,289,931	0.80%
Lumpfish Roe	$949,301	0.59%
Monkfish	$860,510	0.54%
Sea Urchins	$775,221	0.48%
Bluefin Tuna	$490,558	0.31%
Beater Harper Seals Skins	$349,863	0.22%
White Hake	$348,652	0.22%
Molluscs, unspecified	$347,541	0.22%
Clams, Mantels & Body Meat	$278,594	0.17%

Table A.3.8 Twenty Topmost Species by Total Landed Values 2002

Year	2002	
Species	Landed value	Percentage of total
Snow Crab	$115,925,358	69.85%
Northern Shrimp	$9,825,486	5.92%
Yellowtail Flounder	$8,031,783	4.84%
Stimpsons Surf Clams	$5,328,774	3.21%
Cod	$4,389,040	2.64%
Monkfish	$2,792,311	1.68%
Beater Harper Seals Skins	$2,464,279	1.48%
Redfish	$1,884,061	1.14%
Greenland Halibut	$1,637,229	0.99%
Lobster	$1,507,314	0.91%
Atlantic Halibut	$1,301,864	0.78%
Molluscs, unspecified	$1,224,536	0.74%
Quahaugs, Clams	$1,136,832	0.68%
Capelin	$1,110,356	0.67%
American Plaice	$1,108,797	0.67%
Swordfish	$943,853	0.57%
White Hake	$817,914	0.49%
Sea Urchins	$737,170	0.44%
Bluefin Tuna	$543,745	0.33%
Clams, Mantels & Body Meat	$524,873	0.32%

Table A.3.9 Twenty Topmost Species by Total Landed Values 2003

Year	2003	
Species	**Landed value**	**Percentage of total**
Snow Crab	$143,295,252	67.03%
Northern Shrimp	$16,756,074	7.84%
Stimpsons Surf Clams	$12,380,278	5.79%
Yellowtail Flounder	$9,130,179	4.27%
Cockles	$4,006,268	1.87%
Monkfish	$3,551,699	1.66%
Beater Harper Seals Skins	$2,507,552	1.17%
Swordfish	$2,355,023	1.10%
Cod	$2,335,188	1.09%
Greenland Halibut	$2,318,944	1.08%
Capelin	$2,085,434	0.98%
Atlantic Halibut	$1,891,308	0.88%
Redfish	$1,796,628	0.84%
Lobster	$1,338,763	0.63%
Molluscs, unspecified	$1,282,043	0.60%
American Plaice	$1,228,517	0.57%
Clams, Mantels & Body Meat	$1,203,064	0.56%
Sea Urchins	$1,046,133	0.49%
Propellor Clams	$650,616	0.30%
Lumpfish Roe	$559,846	0.26%

Table A.3.10 Twenty Topmost Species by Total Landed Values 2004

Year	2004	
Species	**Landed value**	**Percentage of total**
Snow Crab	$168,583,037	75.37%
Northern Shrimp	$13,669,564	6.11%
Yellowtail Flounder	$9,482,720	4.24%
Stimpsons Surf Clams	$7,457,845	3.33%
Capelin	$3,998,400	1.79%
Cockles	$3,722,574	1.66%
Lumpfish Roe	$2,912,175	1.30%
Swordfish	$2,300,324	1.03%
Greenland Halibut	$1,819,749	0.81%
Redfish	$1,199,643	0.54%
Cod	$1,147,831	0.51%
American Plaice	$1,017,992	0.46%
Sea Urchins	$923,543	0.41%
Atlantic Halibut	$907,130	0.41%
Lobster	$837,407	0.37%
Monkfish	$772,964	0.35%
Clams, Mantels & Body Meat	$750,434	0.34%
Ilex Squid	$360,199	0.16%
Beater Harper Seals Skins	$293,308	0.13%
White Hake	$237,806	0.11%

Table A.3.11 Twenty Topmost Species by Total Landed Values 2005

Year	2005	
Species	**Landed value**	**Percentage of total**
Snow Crab	$96,812,580	60.60%
Northern Shrimp	$16,017,277	10.03%
Yellowtail Flounder	$10,471,013	6.55%
Cockles	$5,559,638	3.48%
Capelin	$4,408,663	2.76%
Stimpsons Surf Clams	$4,227,691	2.65%
Greenland Halibut	$3,040,414	1.90%
Redfish	$2,853,930	1.79%
Swordfish	$2,823,429	1.77%
Mackerel	$1,559,776	0.98%
Atlantic Halibut	$1,392,866	0.87%
Lobster	$1,349,949	0.85%
Cod	$1,266,510	0.79%
Lumpfish Roe	$1,048,976	0.66%
Monkfish	$992,542	0.62%
American Plaice	$965,446	0.60%
Herring	$861,078	0.54%
Sea Urchins	$554,948	0.35%
White Hake	$480,360	0.30%
Hagfish	$346,217	0.22%

Table A.3.12Species Ranking by Cumulative Total Landed Value 1995-2005

Species	Cumulative Value	Percentage	Rank
Snow Crab	$1,082,536,338	68.55%	1
Northern Shrimp	$73,657,139	4.66%	2
Stimpsons Surf Clams	$68,249,708	4.32%	3
Yellowtail Flounder	$62,113,599	3.93%	4
Icelandic Scallops	$33,981,822	2.15%	5
Cod	$32,573,998	2.06%	6
Capelin	$26,403,795	1.67%	7
Redfish	$21,394,395	1.35%	8
Greenland Halibut	$21,050,573	1.33%	9
Swordfish	$18,973,705	1.20%	10
Lobster	$15,910,997	1.01%	11
Cockles	$13,318,721	0.84%	12
Atlantic Halibut	$12,716,980	0.81%	13
Lumpfish Roe	$11,493,994	0.73%	14
Monkfish	$10,322,868	0.65%	15
Beater Harp Seal Skins	$9,210,320	0.58%	16
Sea Urchins	$7,662,067	0.49%	17
American Plaice	$6,727,396	0.43%	18
Bluefin Tuna	$5,960,700	0.38%	19
Stimpsons clams, Mantel and Body Meat	$4,864,942	0.31%	20
Total	**$1,539,124,057**	**97.47%**	

A.3.1.1 Species Ranking by Landed Value

Snow crab is a highly valuable species for the Grand Banks commercial fishery, accounting for more than two-thirds of the cumulative total landed value for the years 1995 to 2005 for all species. Snow Crab landings for that period are worth more than one billion dollars. Northern Shrimp is next with cumulative landings representing less than 5% of all landings from 1995 to 2005. The total landed values of the following species then decrease gradually. Ranked 15th by landed value, Monkfish landings total more than $10 million, whichis only two-thirds of one percent of the total value for all species.We can conclude that the top fifteen species represent a significant proportion of the landed value of all species.The number of species selected for our study is reduced to fifteen as listed in Table A.3.13 below. American Plaice is a historically significant and highly sought after species that has been under moratorium since 1995. Nonetheless, its total landed value puts it in 18th position by cumulative total landed value. It is therefore included in the list of selected species.

Table A.3.13 Selected Species

Selected Species	Species Category
Cod	
Redfish	
Atlantic Halibut	
American Plaice	**Groundfish**
Yellowtail Flounder	
Greenland Halibut	
Monkfish	
Lumpfish Roe	
Swordfish	**Large Pelagic**
Capelin	**Small Pelagic**
Stimpons Surf Clams	
Cockles	
Icelandic Scallops	**Invertebrates**
Lobster	
Northern Shrimp	
Snow Crab	

A.3.1.2 Cockles and Icelandic Scallops

Table A.3.14below shows that data on landed values for Cockles and Icelandic Scallops is problematic. There is a precipitous decline in the landed value of Cockles from a high of

$14,675,655 in 1996 to a low of $0 in 2001 to 2004. However, the landed value of Icelandic Scallops is nil from 1996 to 2002 and increases suddenly to landings worth millions of dollars in 2003 to 2005. Because the data show that the same gear type harvests both species in the same locations, then the decision is to amalgamate these two species (cockles and Icelandic scallops) and treat them as one species for the purpose of our data analysis.

Table A.3.14 Annual Landed Value of Icelandic Scallops and Cockles

Year	Icelandic Scallops	Cockles
1995	$30,242	$9,768,187
1996	$0	$14,764,655
1997	$0	$6,384,624
1998	$0	$2,073,502
1999	$0	$210,109
2000	$0	$490,666
2001	$0	$0
2002	$0	$0
2003	$4,006,268	$0
2004	$3,722,574	$0
2005	$5,559,638	$234,316

A.3.1.3 Updated Species Selection

The final list of selected species in Table A.3.15 reflects the amalgamation of Cockles and Scallops. The species selection captures 95.71% of the total landed value (see Table A.3.15below).

Table A.3.15Updated Species Selection

	Selected Species	Species Category
1	Cod	Groundfish
2	Redfish	
3	Atlantic Halibut	
4	American Plaice	
5	Yellowtail Flounder	
6	Greenland Halibut	
7	Monkfish	
8	Lumpfish Roe	
9	Swordfish	Large Pelagic
10	Capelin	Small Pelagic
11	Stimpons Surf Clams	Invertebrates
12	Cockles and Icelandic Scallops	
13	Lobster	
14	Northern Shrimp	
15	Snow Crab	

A.3.1.4 Naming Conventions

The following naming conventions will be used henceforth:

Simpsons Surf Clams will be referred to as Clams, Icelandic Scallops as Scallops and Lumpfish Roe as Lumpfish.

A.3.2 Gear Type Selection

A second consolidation in the number of ZIFF records can be achieved by keeping only the main gear types that are used to prosecute the species identified above. The following gear types covering the 15 species are selected as noted inTable A.3.16:

Table A.3.16 Selected Gear Types.

Selected Gear Types
Bottom Otter Trawl
Midwater Trawl
Shrimp Trawl
Beach and Bar Seine
Purse Seine
Gillnet
Longline
Hand Line
Trap Net
Pot
Dredge

Table A.3.17below shows the impact of selecting the records containing the gear types listed above. The result is a decrease of only 0.05% relative to the cumulative total landed value for all records from 1995 to 2005, after the species selection has been made. In other words, the species selection captures 95.71% of the total landed value, and the subsequent gear selection reduces the total landed value of remaining records to 95.66%. It is therefore concluded that the selected gear types and species are significant and representative of the entire value for the Grand Banks fleet for the purpose of our study.

Table A.3.17 Impact of Gear Selection on Total Landed Value

	Cumulative Total Landed Value 1995-2005			
Species	All Gears	Percentage	Selected Gears	Percentage
Snow Crab	$1,082,536,338	68.55%	$1,082,536,338	68.55%
Northern Shrimp	$73,657,139	4.66%	$73,645,474	4.66%
Clams	$68,249,708	4.32%	$68,249,708	4.32%
Yellowtail Flounder	$62,113,599	3.93%	$61,720,142	3.91%
Cockles and Scallops	$47,300,544	3.00%	$45,227,042	3.00%
Cod	$32,573,998	2.06%	$32,560,837	2.06%
Capelin	$26,403,795	1.67%	$26,174,554	1.66%
Redfish	$21,394,395	1.35%	$21,394,395	1.35%
Greenland Halibut	$21,050,573	1.33%	$21,050,570	1.33%
Swordfish	$18,973,705	1.20%	$17,728,002	1.20%
Lobster	$15,910,997	1.01%	$14,529,599	1.01%
Atlantic Halibut	$12,716,980	0.81%	$11,689,721	0.81%
Lumpfish	$11,493,994	0.73%	$11,260,277	0.73%
Monkfish	$10,322,868	0.65%	$9,986,399	0.65%
American Plaice	$6,727,396	0.43%	$6,602,187	0.42%
Total	**$1,511,426,028**	**95.71%**	**$1,510,652,947**	**95.66%**

A.3.3 Data Filtering Summary

The selection of species and gear listed above significantly reduces the overall number of records. Table A.3.18below gives a summary of the filtered data, comparing the original number of records to the final number of records and the value of landings for the filtered data to the total value of landings for each year from 1995 to 2005. The total number of records is reduced by 268,463 from 826,521 to 558,058. The selection of a subset of species and gear types from the original dataset greatly reduces the number of records without significant loss in value, and facilitates the data analysis, which is performed in the next section.

Table A.3.18Summary of Filtered Data

Year	1995	1996	1997	1998	1999	2000
Total Number of Records	49667	69284	70750	65501	62535	72565
Remaining number of records	30500	48732	36916	45812	49325	53828
Number of records removed	19167	20552	33834	19689	13210	18737
Total Value	$110,910,332	$83,382,342	$76,664,377	$75,374,234	$139,866,460	$168,950,015
Remaining Value	$105,765,341	$77,070,990	$66,161,685	$71,279,519	$135,683,477	$164,421,030
Percentage of total value	**95.36%**	**92.43%**	**86.30%**	**94.57%**	**97.01%**	**97.32%**

Table A.3.18 **Continued**

Year	2000	2001	2002	2003	2004	2005
Total Number of Records	72565	81125	93187	90837	79361	91709
Remaining number of records	53828	62093	61886	56445	52868	59653
Number of records removed	18737	19032	31301	34392	26493	32056
Total Value	$168,717,781	$160,808,907	$165,971,102	$213,779,833	$223,665,163	$159,751,418
Remaining Value	$164,421,030	$156,238,588	$155,938,565	$205,029,402	$219,828,999	$153,235,351
Percentage of total value	**97.45%**	**97.16%**	**93.96%**	**95.91%**	**98.28%**	**95.92%**

Data Analysis

Now that the significant species and gear have been selected, we turn our attention to the analysis of the Grand Banks commercial fishery, with the aim to obtain the a complete characterization of its dynamics. The first query concerns the variability of landings, i.e. whether they are comparable from one year to the next or vary significantly.Table A.3.19 and Table A.3.20 show the annual landed value by species for the years 1995 to 2005, and Table A.3.21 presents the corresponding percentages.

Total landed values vary dramatically from year to year, from a low of $66,165,278 in 1997 to a high of $219,829,356 in 2004. This trend can be explained in part by changes in landed value of Snow Crab, since it represents such a large portion of the total. However, each species shows large fluctuations in annual landed value from year to year, with the exception of Lobster, which exhibits a steadier, albeit decreasing, pattern. Yellowtail Flounder and Shrimp show large increases in their respective landed values, starting at negligible amounts to over $10.5 million for the former and close to $17 million for the latter. On the other hand, Cockles and Scallops' landed values decline precipitously from a high of nearly $15 million in 1996 to a low of $0 in 2002, rebounding to close to $6 million in 2005. We conclude that landed values can show very large fluctuations from year to year. They are therefore difficult to predict: hence the importance of performing scenario analysis with a wide array of potential future landed values using our model. The analysis continues with the spatial dimension of the landings.

Table A.3.19 Annual Total Landed Values. Selected Species - 1995-2005

Species	Landed Value					
	1995	1996	1997	1998	1999	2000
Cod	$308,802	$363,082	$709,751	$3,909,142	$7,343,855	$5,184,062
Redfish	$56,753	$2,032,233	$1,221,263	$4,920,360	$1,378,108	$877,914
Atlantic Halibut	$591,887	$691,780	$1,254,578	$1,027,125	$813,762	$1,172,981
American Plaice	$59,068	$49,202	$57,839	$189,091	$261,814	$499,698
Yellowtail Flounder	$2,435	$82	$479	$3,025,893	$4,405,653	$7,673,445
Greenland Halibut	$604,614	$2,261,752	$1,139,242	$1,094,690	$928,184	$3,325,562
Monkfish	$142,068	$226,223	$326,920	$336,469	$167,002	$154,160
Lumpfish	$1,303,150	$1,477,793	$964,578	$233,717	$932,765	$755,857
Swordfish	$1,031,307	$1,709,711	$1,611,095	$1,245,703	$2,380,604	$1,145,527
Capelin	$37,017	$2,904,300	$1,508,391	$4,478,694	$1,830,935	$2,037,026
Clams	$15,124,321	$6,016,342	$6,029,082	$769,366	$1,164,688	$2,901,499
Cockles and Scallops	$9,798,429	$14,764,655	$6,384,624	$2,073,502	$210,109	$490,666
Lobster	$1,824,720	$1,635,762	$1,465,839	$1,381,397	$1,629,426	$1,440,791
Northern Shrimp	$0	$8,541	$0	$17,846	$344,442	$7,382,674
Snow Crab	$74,881,660	$42,929,531	$43,488,005	$46,607,851	$111,894,502	$129,417,394
Total	**$105,766,232**	**$77,072,555**	**$66,165,278**	**$71,311,043**	**$135,685,849**	**$164,459,630**

Table A.3.20 Annual Total Landed Values - Selected Species – 2001-2005

Species	Landed Value				
	2001	2002	2003	2004	2005
Cod	$5,616,735	$4,389,040	$2,335,188	$1,147,831	$1,266,510
Redfish	$3,173,501	$1,884,061	$1,796,628	$1,199,643	$2,853,930
Atlantic Halibut	$1,671,699	$1,301,864	$1,891,308	$907,130	$1,392,866
American Plaice	$1,289,931	$1,108,797	$1,228,517	$1,017,992	$965,446
Yellowtail Flounder	$9,889,917	$8,031,783	$9,130,179	$9,482,720	$10,471,013
Greenland Halibut	$2,880,193	$1,637,229	$2,318,944	$1,819,749	$3,040,414
Monkfish	$860,510	$2,792,311	$3,551,699	$772,964	$992,542
Lumpfish	$949,301	$355,837	$559,846	$2,912,175	$1,048,976
Swordfish	$1,427,130	$943,853	$2,355,023	$2,300,324	$2,823,429
Capelin	$2,004,578	$1,110,356	$2,085,434	$3,998,400	$4,408,663
Clams	$6,849,822	$5,328,774	$12,380,278	$7,457,845	$4,227,691
Cockles and Scallops	$55,763	$0	$4,006,268	$3,722,574	$5,793,954
Lobster	$1,499,628	$1,507,314	$1,338,763	$837,407	$1,349,949
Northern Shrimp	$9,635,235	$9,825,486	$16,756,074	$13,669,564	$16,017,277
Snow Crab	$108,701,168	$115,925,358	$143,295,252	$168,583,037	$96,812,580
Total	**$156,505,111**	**$156,142,062**	**$205,029,402**	**$219,829,356**	**$153,465,239**

Table A.3.21 Percentage of Total Annual Landed Values - Selected Species

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Species	Percentage										
Cod	0.28%	0.44%	0.93%	5.19%	5.25%	3.07%	3.49%	2.64%	1.09%	0.51%	0.79%
Redfish	0.05%	2.44%	1.59%	6.53%	0.99%	0.52%	1.97%	1.14%	0.84%	0.54%	1.79%
Atlantic Halibut	0.53%	0.83%	1.64%	1.36%	0.58%	0.69%	1.04%	0.78%	0.88%	0.41%	0.87%
American Plaice	0.05%	0.06%	0.08%	0.25%	0.19%	0.30%	0.80%	0.67%	0.57%	0.46%	0.60%
Yellowtail Flounder	0.00%	0.00%	0.00%	4.01%	3.15%	4.54%	6.15%	4.84%	4.27%	4.24%	6.55%
Greenland Halibut	0.55%	2.71%	1.49%	1.45%	0.66%	1.97%	1.79%	0.99%	1.08%	0.81%	1.90%
Monkfish	0.13%	0.27%	0.43%	0.45%	0.12%	0.09%	0.54%	1.68%	1.66%	0.35%	0.62%
Lumpfish	1.17%	1.77%	1.26%	0.31%	0.67%	0.45%	0.59%	0.21%	0.26%	1.30%	0.66%
Swordfish	0.93%	2.05%	2.10%	1.65%	1.70%	0.68%	0.89%	0.57%	1.10%	1.03%	1.77%
Capelin	0.03%	3.48%	1.97%	5.94%	1.31%	1.21%	1.25%	0.67%	0.98%	1.79%	2.76%
Clams	13.64%	7.22%	7.86%	1.02%	0.83%	1.72%	4.26%	3.21%	5.79%	3.33%	2.65%
Cockles and Scallops	8.84%	17.71%	8.33%	2.75%	0.15%	0.29%	0.03%	0.00%	1.87%	1.66%	3.63%
Lobster	1.65%	1.96%	1.91%	1.83%	1.16%	0.85%	0.93%	0.91%	0.63%	0.37%	0.85%
Northern Shrimp	0.00%	0.01%	0.00%	0.02%	0.25%	4.37%	5.99%	5.92%	7.84%	6.11%	10.03%
Snow Crab	67.52%	51.49%	56.73%	61.84%	80.00%	76.60%	67.60%	69.85%	67.03%	75.37%	60.60%
Total	**95.36%**	**92.43%**	**86.31%**	**94.61%**	**97.01%**	**97.34%**	**97.32%**	**94.08%**	**95.91%**	**98.29%**	**96.07%**

A.4 Spatial Analysis

Each record in a ZIFF contains information about the location of the catch. This information is used to examine the spatial distribution of the catch between NAFO divisions 3L, 3N and 3O (See Figure A.12.1).Following are tables and graphs detailing the landed values and landed weights by species and by gear types in each of the areas 3L, 3N and 3O.

Spatial data analysis results in several observations as noted below:

- Cod, Lobster, Northern Shrimp, Capelin and Snow Crab are primarily captured in NAFO division 3O.
- Greenland Halibut is also mainly captured in 3L with 3O accounting for a maximum of 37% of total catch.
- Redfish and Monkfish are captured in significant amounts in area 3O.
- Atlantic Halibut originates mainly from 3O with the exception of the year 2001 that sees an increase in 3L's share of the catch and a decrease of 3N's share in 2002.
- American Plaice sees a large increase in catch in 2001 with the majority of the catch occurring in 3N.
- Swordfish harvests take place mainly in area 3O with 3N accounting for a maximum of 49% of total catch in 1999.
- Scallop catches originate mainly from area 3N with 3L accounting for a maximum of 17% of total catches in 2001.

Cod, Lobster, Northern Shrimp, Capelin and Snow Crab are primarily captured in NAFO division 3O. Greenland Halibut is also mainly captured in 3L with 3O accounting for a maximum of 37% of total catch. Redfish and Monkfish are captured in significant amounts in area 3O. Atlantic Halibut originates mainly from 3O with the exception of the year 2001 that sees an increase in 3L's share of the catch and a decrease of 3N's share in 2002. American Plaice sees a large increase in catch in 2001 with the majority of the catch occurring in 3N. Swordfish harvests take place mainly in area 3O with 3N accounting for a maximum of 49% of total catch in 1999. Scallop catches originate mainly from area 3N with 3L accounting for a maximum of 17% of total catches in 2001.

The distribution of the landed weights according to their area of origin shows a clear localization of the origin of the catch. This warrants a further analysis of the spatial distribution of the catch by the subdivision of areas 3L, 3N and 3O, a task that will be performed in section A.8. The graphs also show a clear pattern of high variabilityin landed value and landed weight from year to year and are representative of all species. A notable exception is Lobster, which shows an overall decline in yearly landed value and landed weight. In addition, the average annual real landed price per kg (in 2005 dollars) shows variations depending on the area of origin of the catch. The analysis of the landed value, the landed weight and the resulting landed price of the catch by area clearly shows the importance of taking into account the area of origin when formulation our model as each of these components vary significantly by location. Next, we examine the seasonality of the catch before performing a more detailed spatial analysis of the catch

Table A.4.1 Yearly Landed Value By Species – Area 3L. Years 1995 - 2005

Species	1995	1996	1997	1998	1999	2000
Cod	$190,209	$234,730	$338,191	$3,289,897	$6,591,894	$4,893,085
Redfish	$992	$560	$28,547	$322	$264	$18,096
Atlantic Halibut	$7,819	$25,535	$673	$168	$36,030	$487
American Plaice	$48,466	$33,566	$12,972	$9,768	$9,865	$131,638
Greenland Halibut	$425,870	$1,644,100	$918,836	$933,982	$779,383	$2,812,225
Monkfish	$9,826	$42,951	$61	$0	$0	$0
Lumpfish	$1,303,150	$1,480,298	$964,578	$233,717	$932,765	$755,857
Swordfish	$584,545	$585,913	$271,896	$0	$0	$0
Capelin	$37,017	$2,904,300	$1,508,391	$4,478,694	$1,830,935	$2,037,026
Clams	$0	$4,931	$0	$0	$0	$1,884
Cockles and Scallops	$201,422	$490,194	$611,599	$283,350	$10,473	$60,810
Lobster	$1,824,720	$1,635,762	$1,465,839	$1,381,397	$1,629,426	$1,440,791
Northern Shrimp	$0	$0	$0	$10,861	$342,073	$7,360,293
Snow Crab	$74,803,844	$41,820,555	$40,655,324	$45,191,223	$89,663,171	$109,268,720

Species	2001	2002	2003	2004	2005
Cod	$4,864,856	$3,778,721	$1,232,749	$531,787	$723,727
Redfish	$14,496	$30,569	$5,206	$1,974	$2,884
Atlantic Halibut	$122,503	$57,056	$22,053	$4,301	$7,658
American Plaice	$180,439	$183,807	$72,849	$48,724	$66,642
Greenland Halibut	$2,490,531	$1,497,457	$1,766,354	$1,516,985	$2,758,564
Monkfish	$0	$12	$4,543	$0	$0
Lumpfish	$949,301	$355,837	$559,846	$2,912,175	$1,048,976
Swordfish	$0	$0	$0	$0	$0
Capelin	$2,004,578	$1,110,356	$2,085,434	$3,998,400	$4,179,422
Clams	$34,200	$0	$0	$2,498	$0
Cockles and Scallops	$9,643	$0	$0	$2,112	$7,581
Lobster	$1,499,628	$1,507,314	$1,338,763	$837,407	$1,349,949
Northern Shrimp	$9,635,235	$9,823,990	$16,756,074	$13,669,207	$16,004,395
Snow Crab	$90,558,097	$96,500,196	$117,843,907	$139,589,283	$80,310,750

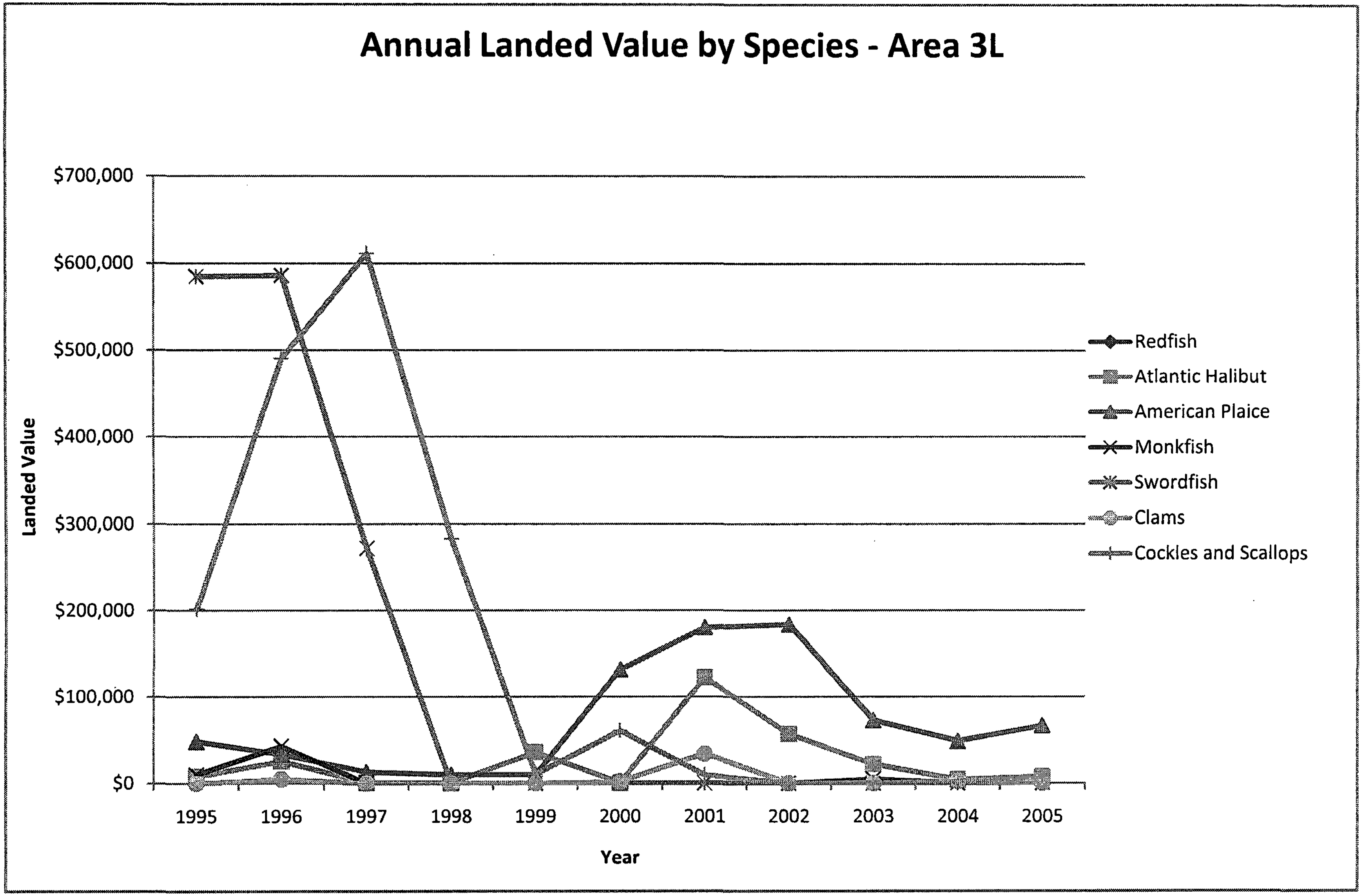

Figure A.4.1 Annual Landed Value by Species - Area 3L. Redfish, Atlantic Halibut, American Plaice, Monkfish, Swordfish, Clams, Cockles and Scallops. Years 1995-2005.

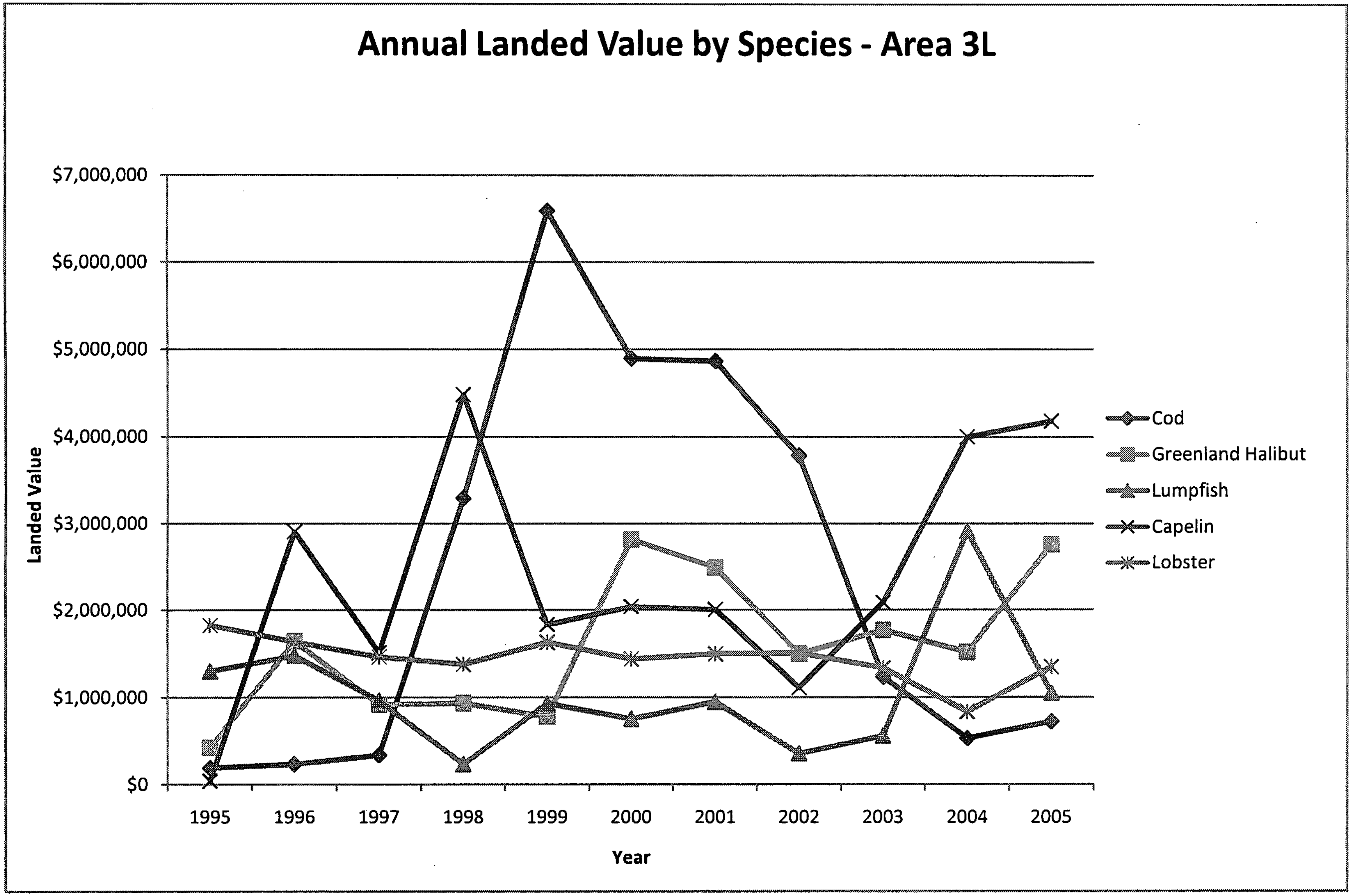

Figure A.4.2 Annual Landed Value by Species - Area 3L. Cod, Greenland Halibut, Lumpfish, Capelin, Lobster. Years 1995-2005.

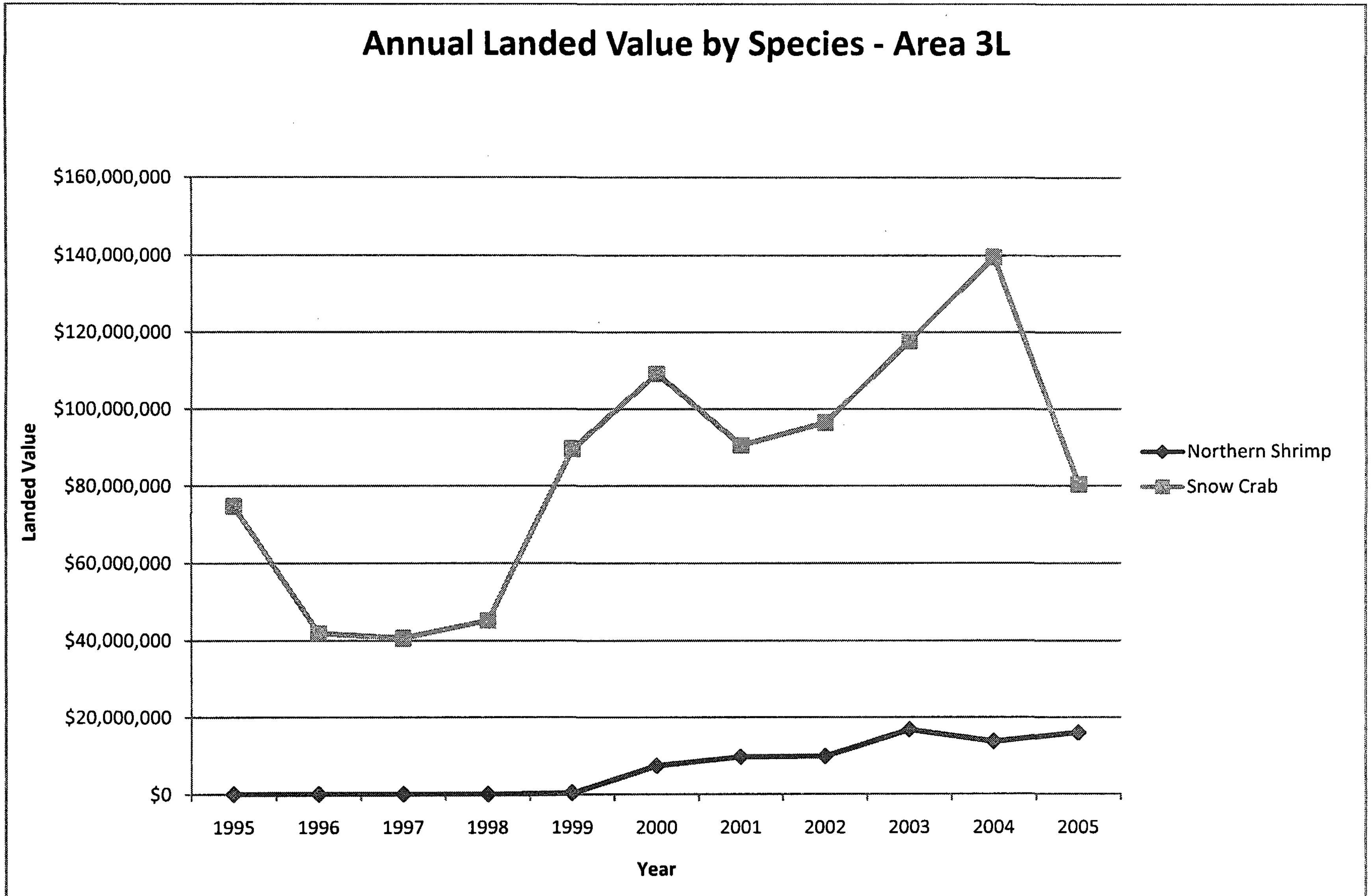

Figure A.4.3 Annual Landed Value by Species - Area 3L. Northern Shrimp, Snow Crab. Years 1995-2005.

Table A.4.2 Annual Landed Value by Species – Area 3N

Species	1995	1996	1997	1998	1999	2000
Cod	$149	$14,165	$67,055	$123,173	$130,557	$136,947
Redfish	$0	$0	$1,022	$4,057	$2,915	$0
Atlantic Halibut	$36,262	$34,252	$174,297	$148,559	$299,591	$722,906
American Plaice	$91	$1,466	$9,531	$107,637	$209,542	$332,519
Greenland Halibut	$0	$0	$45	$6,152	$0	$2,448
Monkfish	$4,412	$0	$652	$0	$0	$67
Lumpfish	$0	$0	$0	$0	$0	$0
Swordfish	$0	$14,868	$320,610	$367,606	$1,044,272	$332,217
Capelin	$0	$0	$0	$0	$0	$0
Clams	$15,124,321	$6,010,533	$6,029,082	$769,366	$1,164,688	$2,899,615
Cockles and Scallops	$9,596,783	$14,274,461	$5,717,987	$1,786,798	$199,636	$429,857
Lobster	$0	$0	$0	$0	$0	$0
Northern Shrimp	$0	$0	$0	$0	$0	$21,922
Snow Crab	$0	$21,411	$128,432	$296,711	$10,559,467	$12,293,320

Species	2001	2002	2003	2004	2005
Cod	$243,827	$189,533	$227,800	$142,755	$224,092
Redfish	$12,045	$0	$0	$0	$908
Atlantic Halibut	$551,137	$90,004	$307,185	$178,747	$428,469
American Plaice	$685,964	$674,732	$707,633	$588,653	$659,571
Greenland Halibut	$115	$9	$756	$2,697	$6,528
Monkfish	$2,634	$630	$0	$0	$78
Lumpfish	$0	$0	$0	$0	$0
Swordfish	$608,976	$279,207	$191,624	$211,228	$191,259
Capelin	$0	$0	$0	$0	$0
Clams	$0	$0	$0	$0	$0
Cockles and Scallops	$46,120	$0	$0	$0	$190,603
Lobster	$0	$0	$0	$0	$0
Northern Shrimp	$0	$0	$0	$0	$2,091
Snow Crab	$10,864,855	$12,491,340	$15,277,981	$17,886,625	$10,346,397

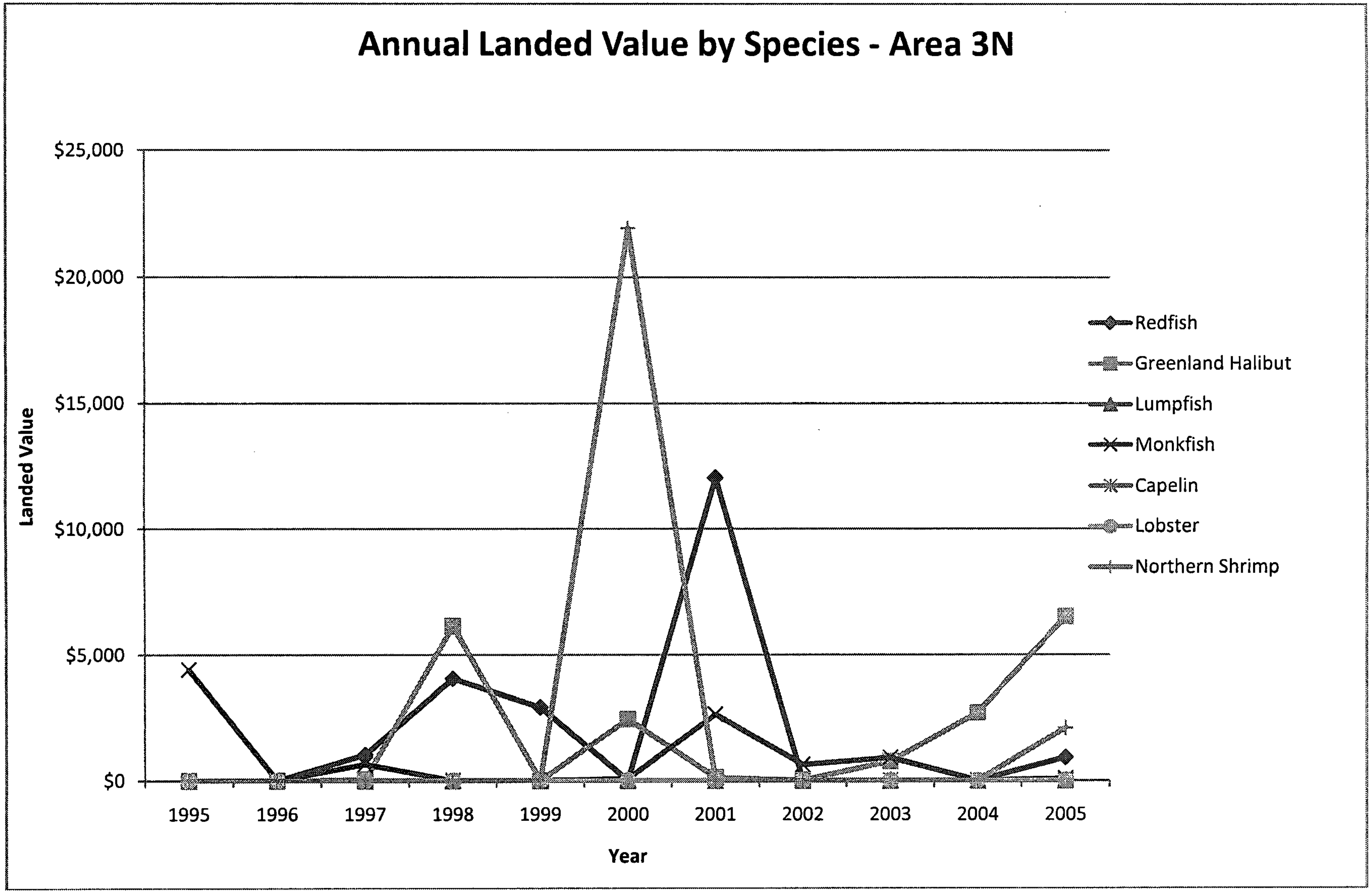

Figure A.4.4 Annual Landed Value by Species – Area 3N. Redfish, Greenland Halibut, Lumpfish, Monkfish, Capelin, Lobster, Northern Shrimp. Years 1995-2005

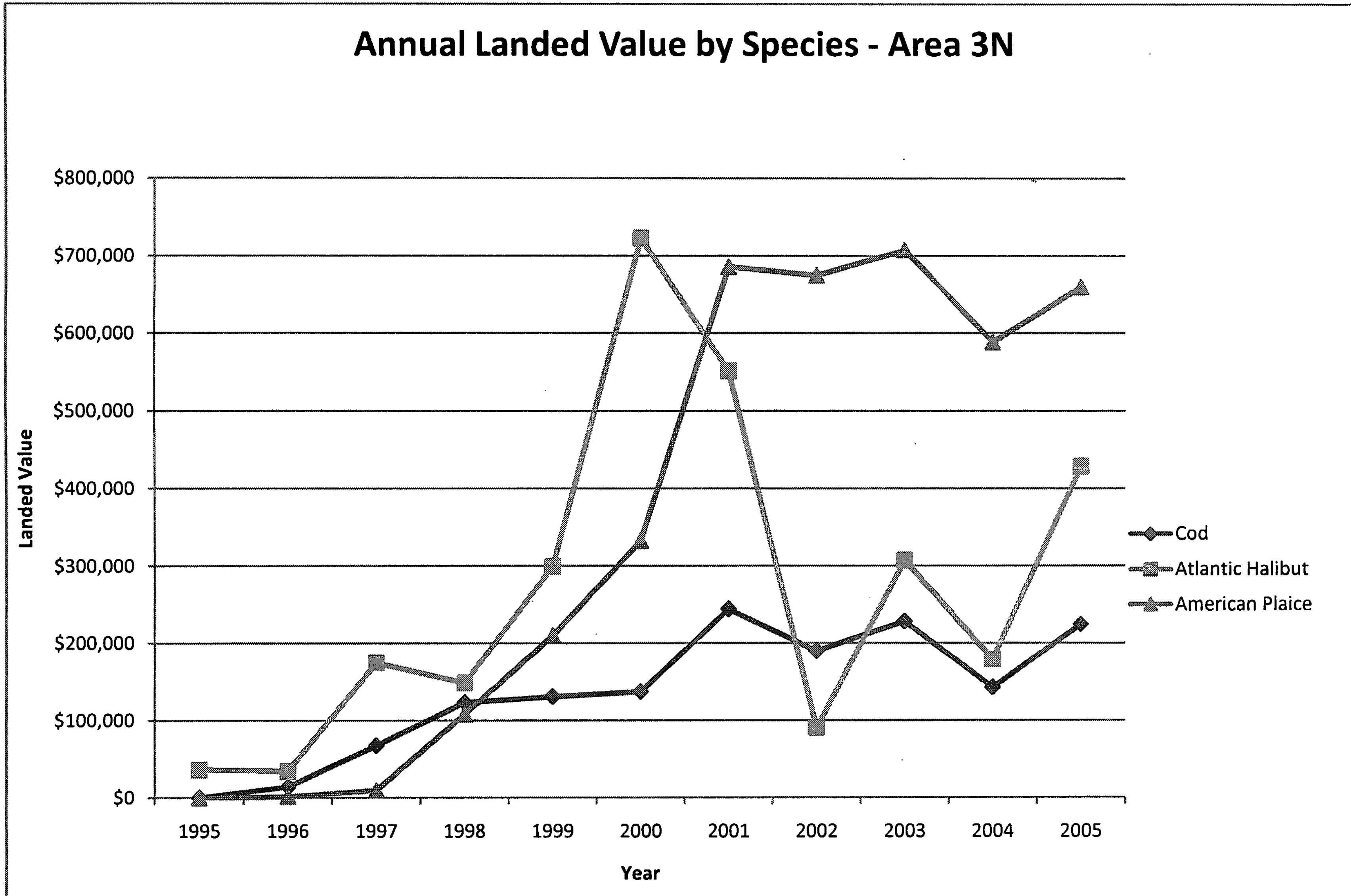

Figure A.4.5 Annual Landed Value by Species - Area 3N. Cod, Atlantic Halibut, American Plaice. Years 1995-2005

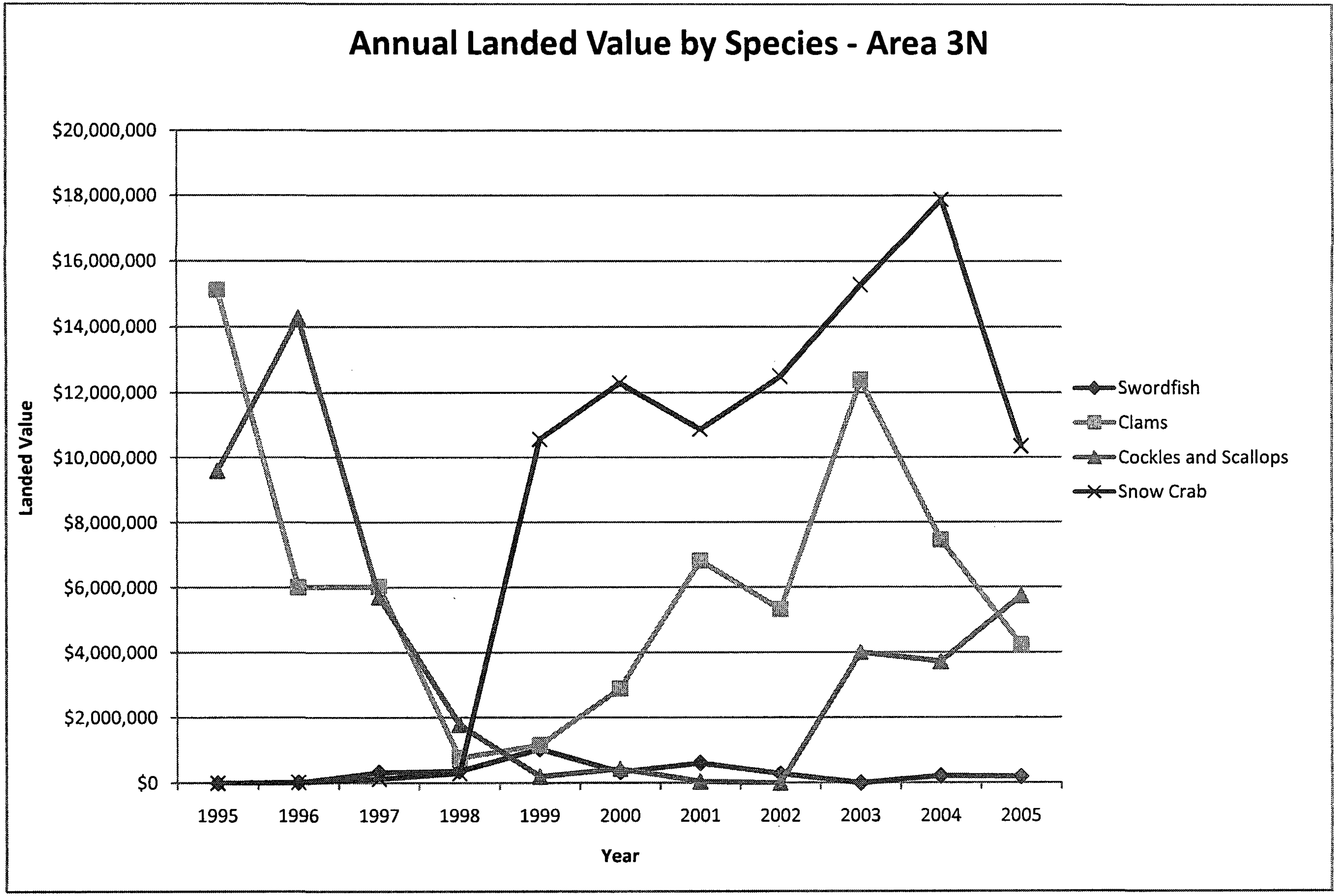

Figure A.4.6 Annual Landed Value by Species - Area 3N. Swordfish, Clams, Cockles and Scallops, Snow Crab. Years 1995-2005

Table A.4.3 Annual Landed Values by Species – Area 3O. 1995-2005

Species	1995	1996	1997	1998	1999	2000
Cod	$117,568	$114,186	$304,506	$494,352	$621,403	$150,420
Redfish	$55,762	$2,031,673	$1,191,694	$4,915,981	$1,374,930	$859,819
Atlantic Halibut	$547,806	$631,993	$1,079,608	$878,188	$478,141	$449,588
American Plaice	$10,496	$14,170	$35,336	$69,989	$42,407	$32,718
Greenland Halibut	$178,744	$617,652	$220,361	$154,555	$148,797	$510,888
Monkfish	$127,830	$183,272	$326,207	$336,469	$167,002	$154,093
Lumpfish	$0	$0	$0	$0	$0	
Swordfish	$446,762	$1,108,930	$1,018,589	$878,096	$1,336,332	$813,311
Capelin	$0	$0	$0	$0	$0	$0
Clams	$0	$877	$0	$0	$0	$0
Cockles and Scallops	$224	$0	$55,038	$3,353	$0	$0
Lobster	$0	$0	$0	$0	$0	$0
Northern Shrimp	$0	$8,541	$0	$0	$0	$0
Snow Crab	$77,816	$1,087,565	$2,704,249	$1,119,918	$11,671,864	$7,855,354

Species	2001	2002	2003	2004	2005
Cod	$501,746	$420,785	$874,639	$473,289	$318,043
Redfish	$3,146,961	$1,853,492	$1,791,423	$1,197,668	$2,850,138
Atlantic Halibut	$998,060	$1,154,669	$1,562,070	$724,082	$956,739
American Plaice	$352,498	$200,613	$448,035	$380,614	$239,169
Greenland Halibut	$389,547	$139,763	$551,834	$300,067	$275,322
Monkfish	$857,876	$2,791,669	$3,546,252	$772,964	$992,463
Lumpfish	$0	$0	$0	$0	$0
Swordfish	$818,154	$664,646	$2,163,399	$2,089,097	$2,632,170
Capelin	$0	$0	$0	$0	$0
Clams	$0	$0	$0	$0	$0
Cockles and Scallops	$0	$0	$0	$0	$36,132
Lobster	$0	$0	$0	$0	$0
Northern Shrimp	$0	$0	$0	$0	$0
Snow Crab	$7,278,216	$6,933,822	$10,173,364	$11,107,129	$6,155,433

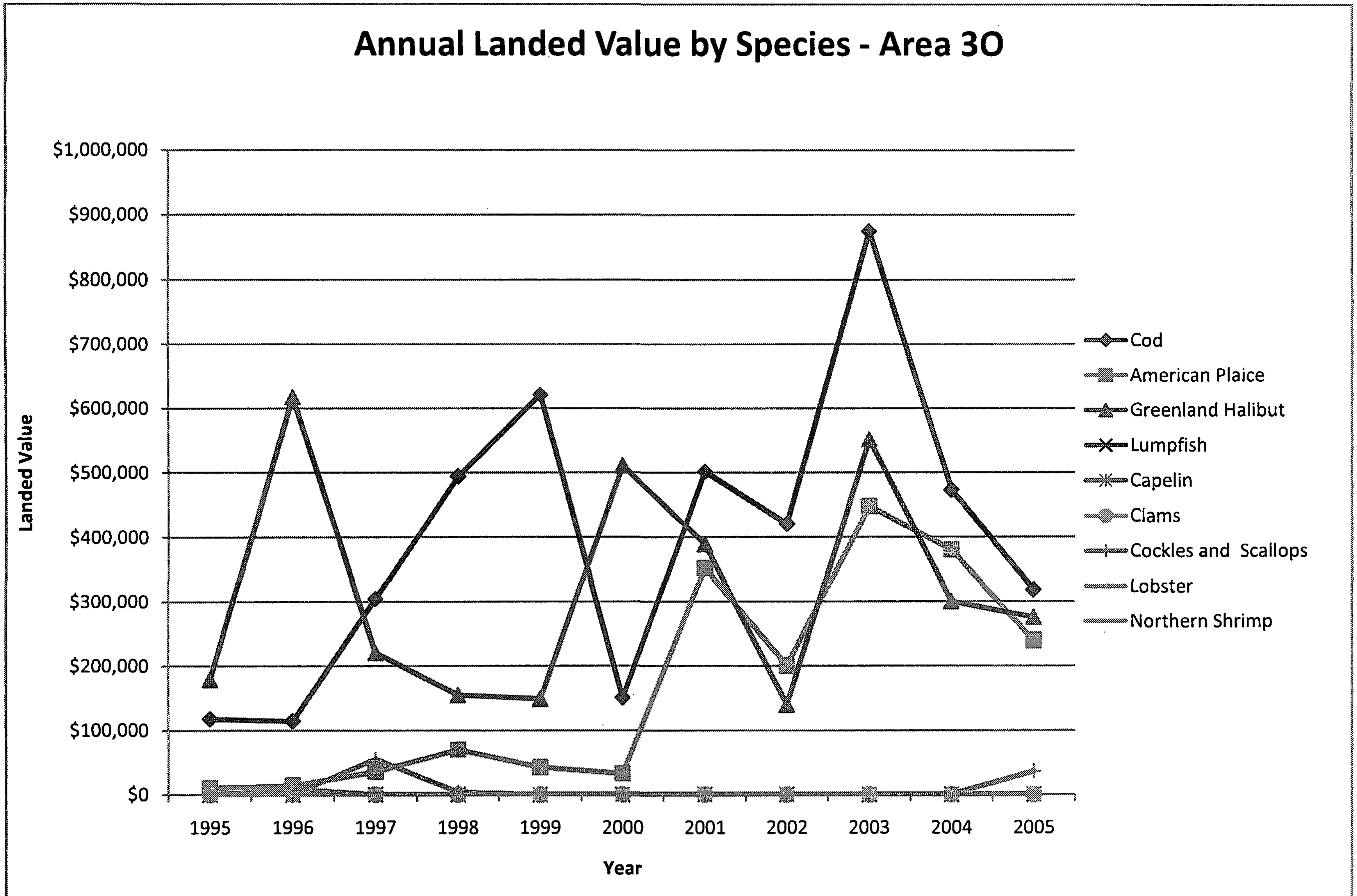

Figure A.4.7 Annual Landed Value by Species - Area 3O. Cod, American Plaice, Greenland Halibut, Lumpfish, Capelin. Years 1995-2005.

Table A.4.4 Annual Landed Value by Gear Type – Area 3L

Gear	1995	1996	1997	1998	1999	2000
Bottom Otter Trawl	$3,622	$2,127	$29,758	$6,871	$245	$2,062,685
Midwater Trawl	$0	$0	$0	$0	$0	$0
Shrimp Trawl	$0	$0	$0	$10,861	$342,073	$7,360,293
Beach and Bar Seine	$31,766	$32,831	$9,135	$77,353	$42,179	$294,400
Purse Seine	$0	$1,353,704	$1,464,046	$2,761,536	$1,292,644	$871,488
Gillnet	$1,940,482	$3,391,195	$2,151,533	$3,264,819	$7,698,236	$6,977,507
Longline	$608,696	$622,492	$296,042	$455,904	$122,530	$269,445
Hand Line	$7,247	$13,179	$22,226	$712,039	$490,096	$387,407
Trap Net	$15,424	$1,536,475	$71,464	$1,670,542	$537,546	$927,800
Pot	$76,629,358	$43,456,318	$42,121,163	$46,572,621	$91,292,597	$110,709,465
Dredge	$201,422	$495,126	$611,599	$283,350	$10,473	$62,693

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	$1,131,378	$1,121,792	$1,860,057	$1,201,673	$834,433
Midwater Trawl	$0	$0	$0	$0	$0
Shrimp Trawl	$9,635,235	$9,823,994	$16,756,074	$13,669,207	$16,004,395
Beach and Bar Seine	$135,246	$78,539	$176,910	$475,005	$1,234,294
Purse Seine	$1,139,065	$714,990	$1,153,852	$1,925,510	$1,890,737
Gillnet	$6,640,495	$4,125,034	$771,670	$4,025,211	$4,152,281
Longline	$258,065	$99,897	$20,803	$14,560	$918
Hand Line	$586,129	$439,451	$1,035,831	$74	$0
Trap Net	$888,280	$456,634	$754,673	$1,597,885	$1,054,391
Pot	$92,057,725	$98,007,510	$119,182,670	$140,426,690	$81,714,619
Dredge	$43,843	$0	$0	$4,610	$7,581

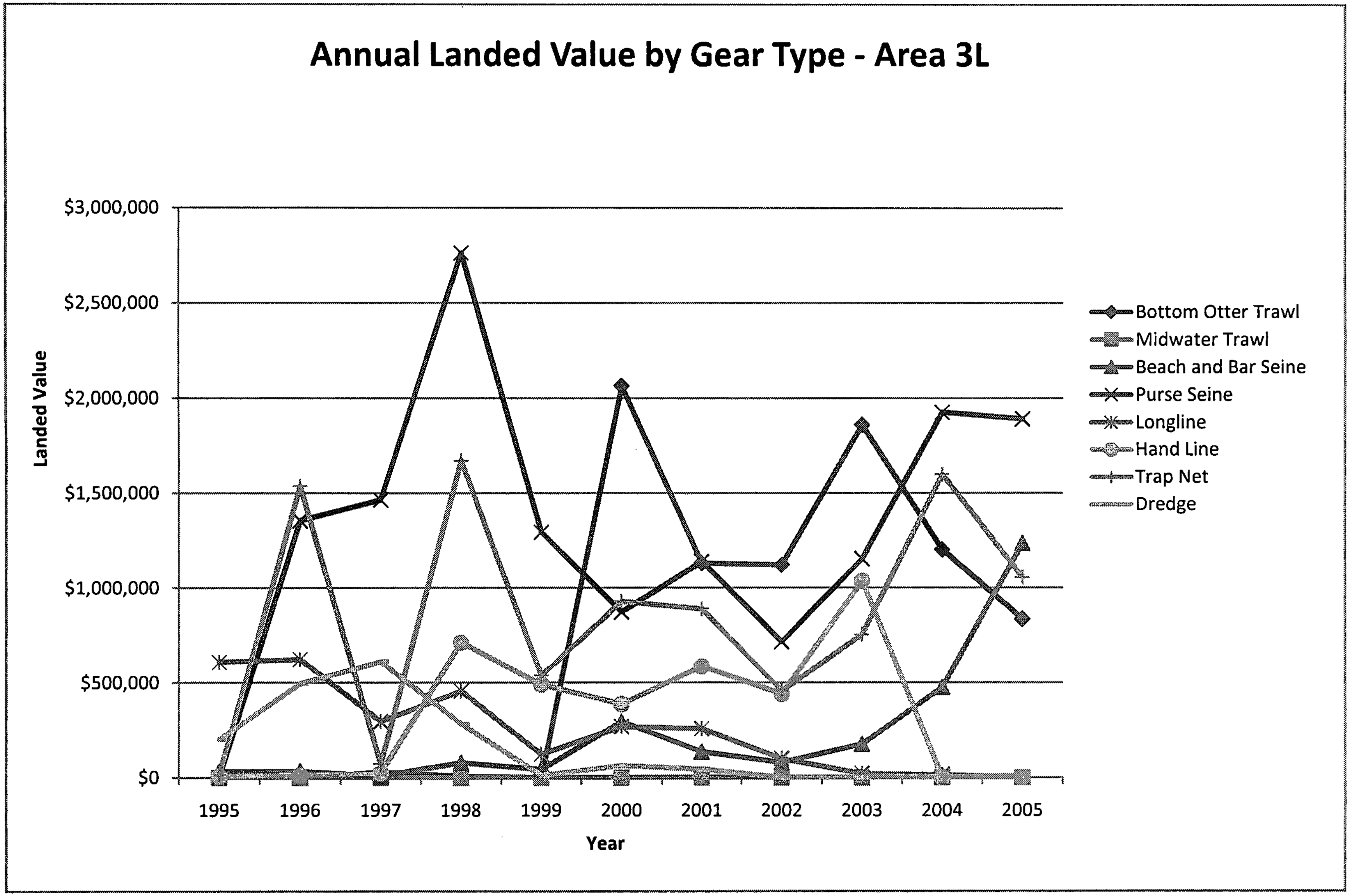

Figure A.4.8 Annual Landed Value by Gear Type - Area 3L. Bottom Otter Trawl, Midwater Trawl, Beach and Bar Seine. Years 1995-2005.

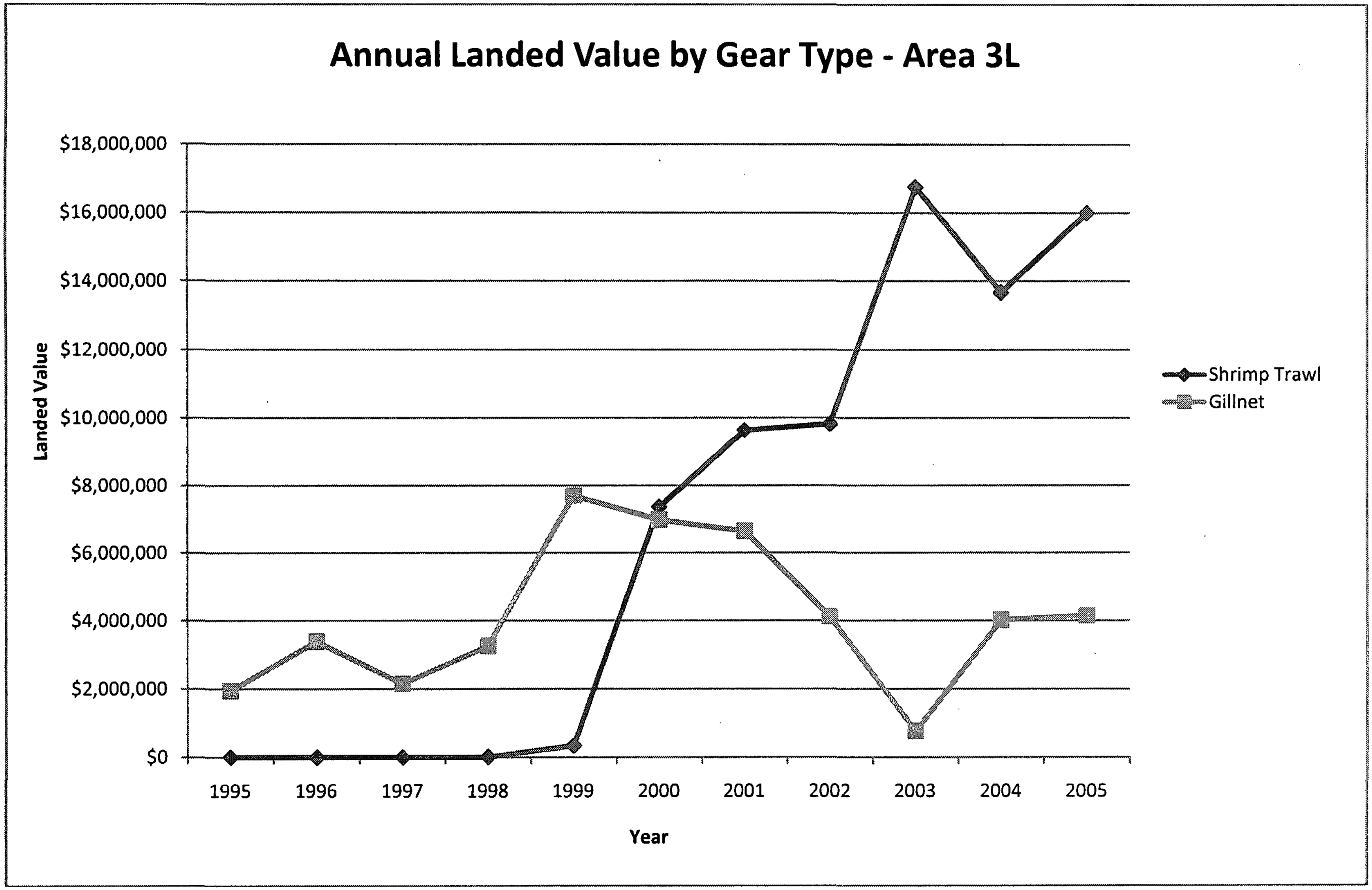

Figure A.4.9 Annual Landed Value by Gear Type - Area 3L. Shrimp Trawl, Gillnet. Years 1995-2005

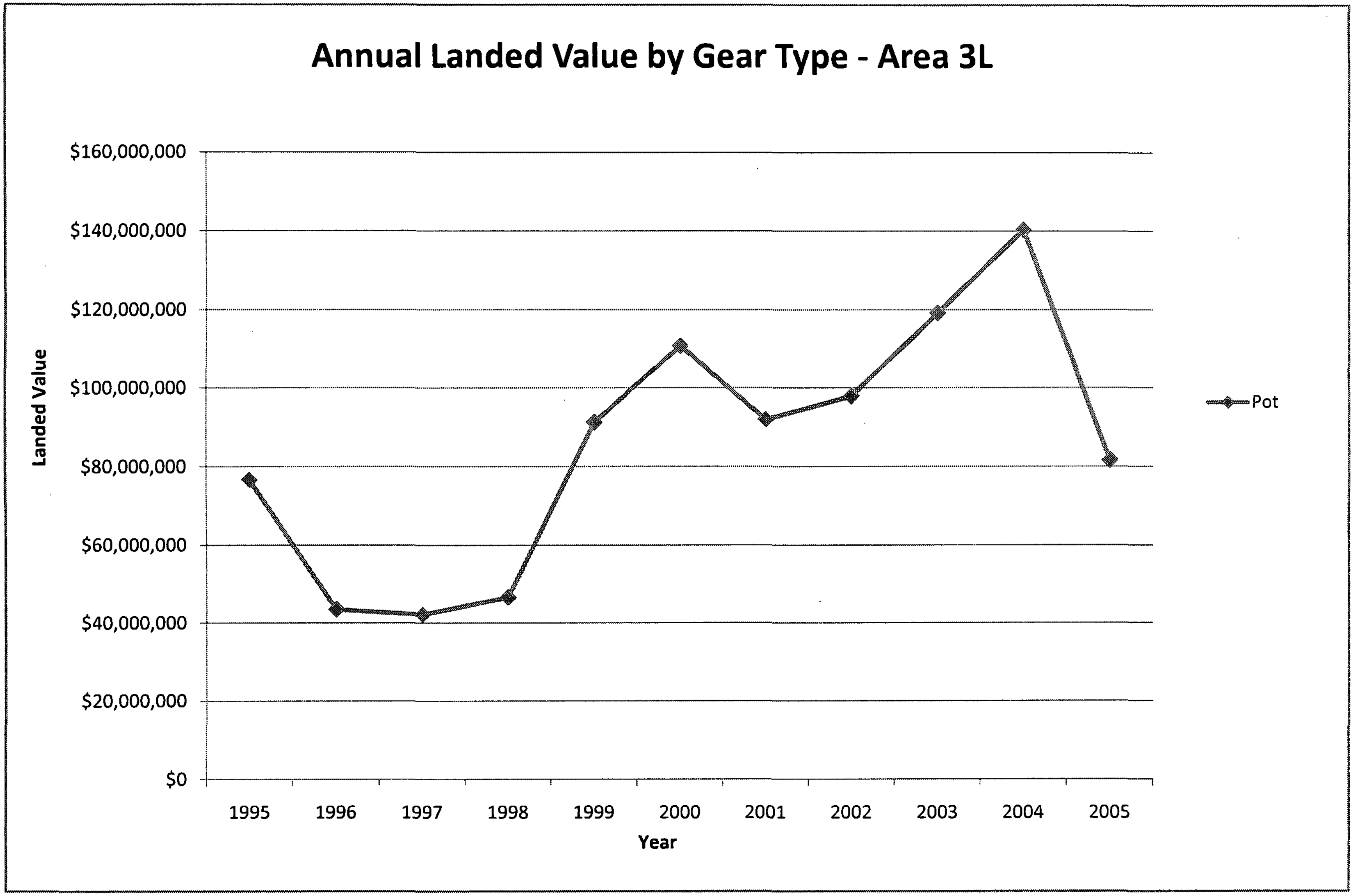

Figure A.4.10 Annual Landed Value by Gear Type - Area 3L. Pot. Years 1995-2005

Table A.4.5 Annual Landed Value by Gear Type – Area 3N.

Gear	1995	1996	1997	1998	1999	2000
Bottom Otter Trawl	$50	$0	$2,001	$2,635,412	$1,112,472	$6,724,692
Midwater Trawl	$0	$0	$0	$0	$3,494,740	$0
Shrimp Trawl	$0	$0	$0	$0	$0	$21,922
Beach and Bar Seine	$0	$0	$0	$0	$0	$0
Purse Seine	$0	$0	$0	$0	$0	$0
Gillnet	$11,017	$1,553	$77,136	$0	$25,011	$1,335
Longline	$29,847	$63,203	$494,494	$525,241	$1,376,122	$1,074,559
Hand Line	$0	$0	$0	$0	$0	$0
Trap Net	$0	$0	$0	$0	$0	$0
Pot	$0	$21,411	$128,432	$296,711	$10,559,467	$12,293,320
Dredge	$24,721,104	$20,284,994	$11,747,069	$2,556,164	$1,364,324	$3,329,472

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	$7,984,907	$7,135,277	$6,869,948	$7,384,793	$9,294,165
Midwater Trawl	$0	$0	$0	$0	$0
Shrimp Trawl	$0	$0	$0	$0	$2,091
Beach and Bar Seine	$0	$0	$0	$0	$0
Purse Seine	$0	$0	$0	$0	$0
Gillnet	$1,820	$0	$0	$0	$6,546
Longline	$1,158,899	$316,072	$484,947	$386,874	$635,272
Hand Line	$0	$0	$0	$0	$0
Trap Net	$0	$0	$0	$0	$0
Pot	$10,864,855	$12,491,340	$15,277,981	$17,886,625	$10,346,397
Dredge	$6,861,742	$5,328,774	$16,386,255	$11,175,810	$9,977,932

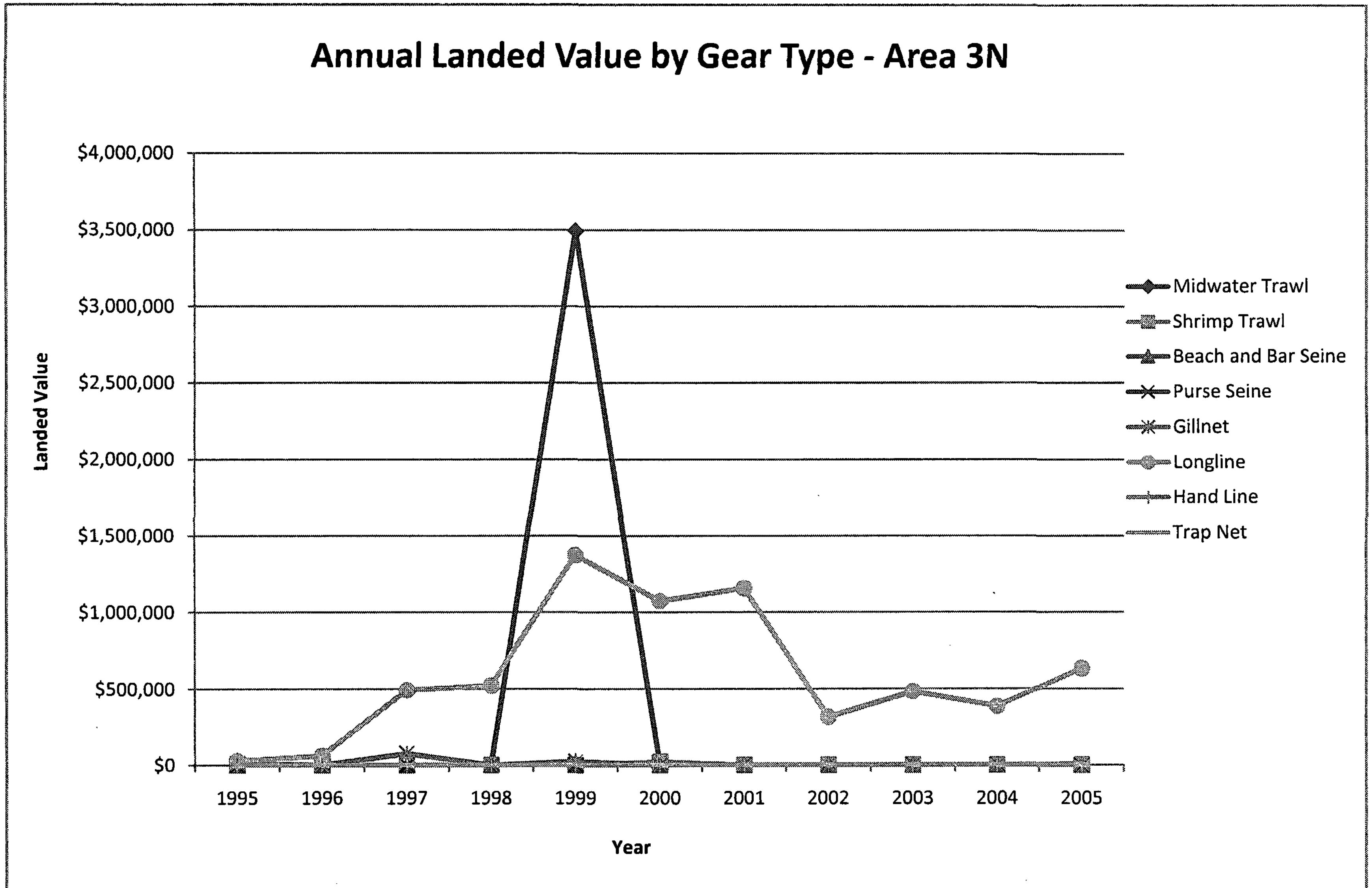

Figure A.4.11 Annual Landed Value by Gear Type - Area 3N. Midwater Trawl, Shrimp Trawl, Beach and Bar Seine, Gillnet, Longline, Hand Line, Trap Net. Years 1995-2005.

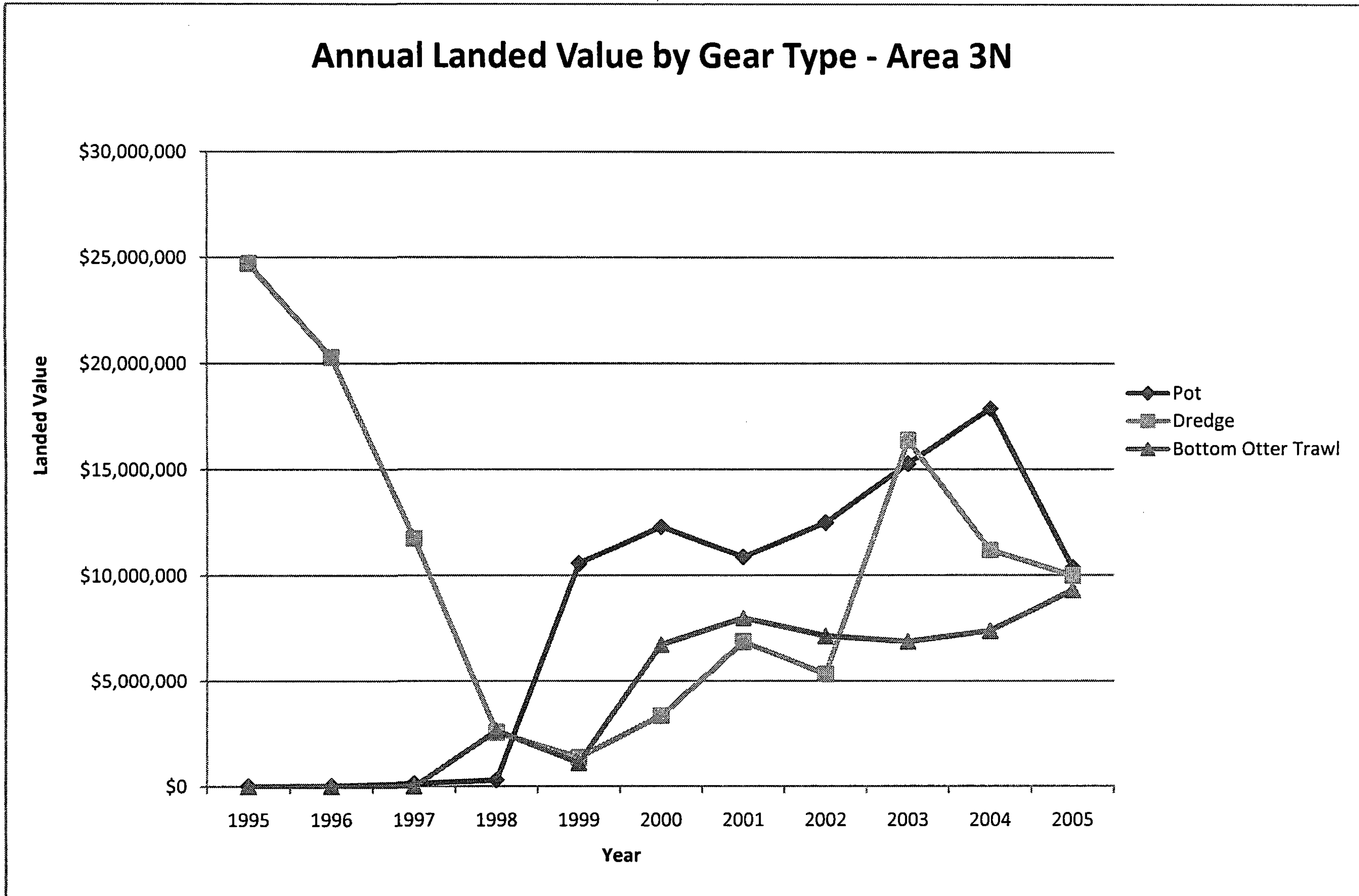

Figure A.4.12 Annual Landed Value by Gear Type - Area 3N. Pot, Dredge, Bottom Otter Trawl. Years 1995-2005.

Table A.4.6 Annual Landed Value by Gear Type – Area 3O.

Gear	1996	1996	1997	1998	1999	2000
Bottom Otter Trawl	$105,476	$2,058,890	$1,406,636	$5,837,204	$1,395,252	$1,157,044
Midwater Trawl	$41,781	$48,199	$4,649	$0	$260,804	$25,150
Shrimp Trawl	$0	$8,541	$0	$0	$0	$0
Beach and Bar Seine	$0	$0	$0	$0	$0	$0
Purse Seine	$0	$0	$0	$0	$0	$0
Gillnet	$341,410	$971,407	$1,081,735	$954,353	$941,559	$947,993
Longline	$998,598	$1,623,407	$1,683,282	$1,535,268	$1,653,244	$1,067,006
Hand Line	$0	$0	$0	$0	$0	$0
Trap Net	$0	$0	$0	$0	$0	$0
Pot	$77,816	$1,087,565	$2,704,249	$1,119,918	$11,671,864	$7,855,354
Dredge	$224	$877	$55,038	$3,353	$0	$0

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	$6,458,764	$4,076,043	$6,077,062	$4,659,174	$5,136,087
Midwater Trawl	$0	$0	$0	$0	$0
Shrimp Trawl	$0	$0	$0	$0	$0
Beach and Bar Seine	$0	$0	$0	$0	$0
Purse Seine	$0	$0	$0	$0	$0
Gillnet	$1,520,615	$3,434,968	$4,486,266	$1,266,880	$1,490,126
Longline	$1,593,310	$1,354,429	$3,732,234	$2,688,167	$3,304,578
Hand Line	$0	$0	$0	$0	$0
Trap Net	$0	$0	$0	$0	$0
Pot	$7,278,216	$6,933,822	$10,173,364	$11,107,129	$6,155,433
Dredge	$0	$0	$291	$0	$36,132

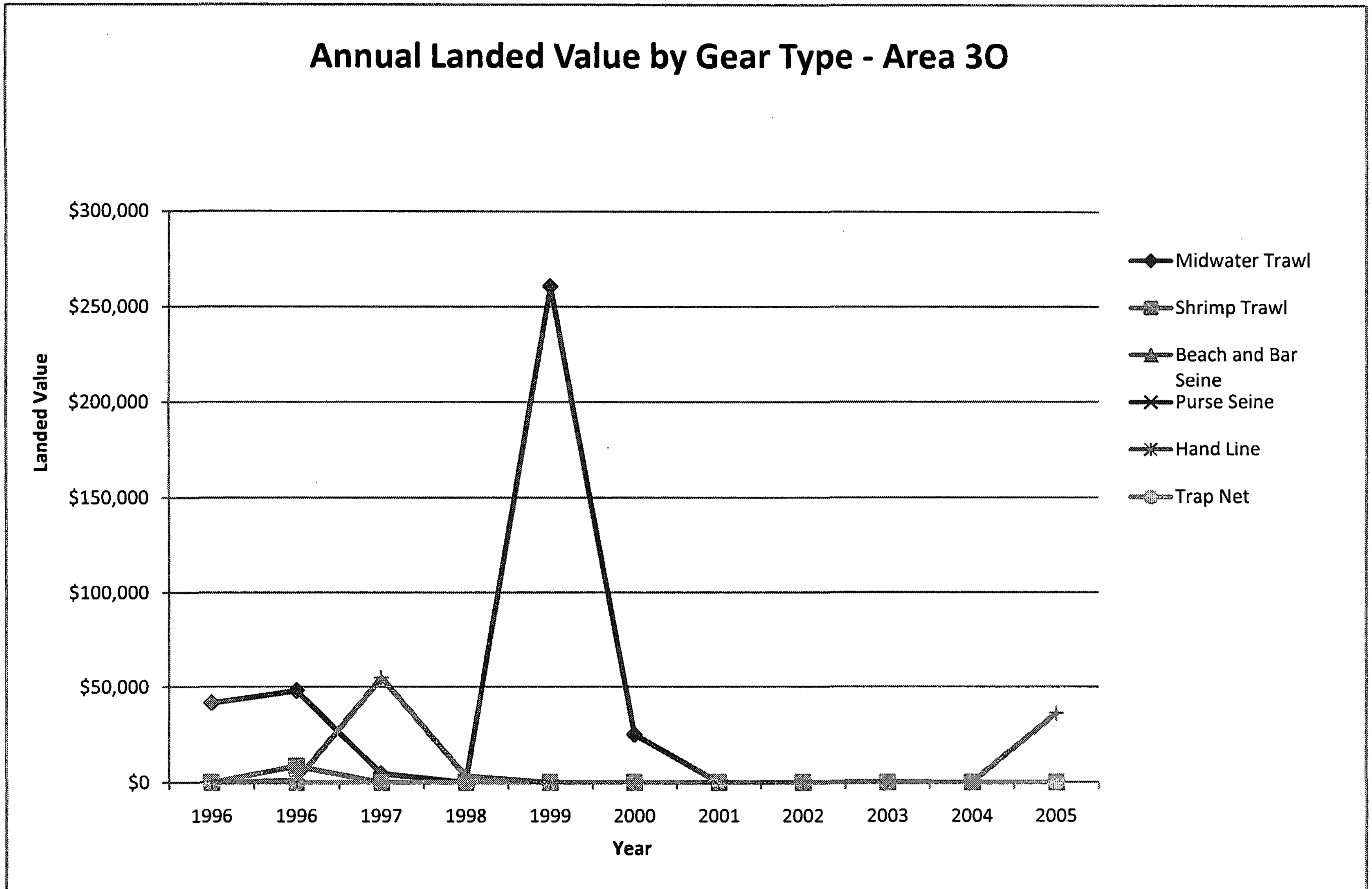

Figure A.4.13 Annual Landed Value by Gear Type – Area 3O. Midwater Trawl, Shrimp Trawl, Beach and Bar Seine, Purse Seine, Hand Line, Trap Net. Years 1995-2005.

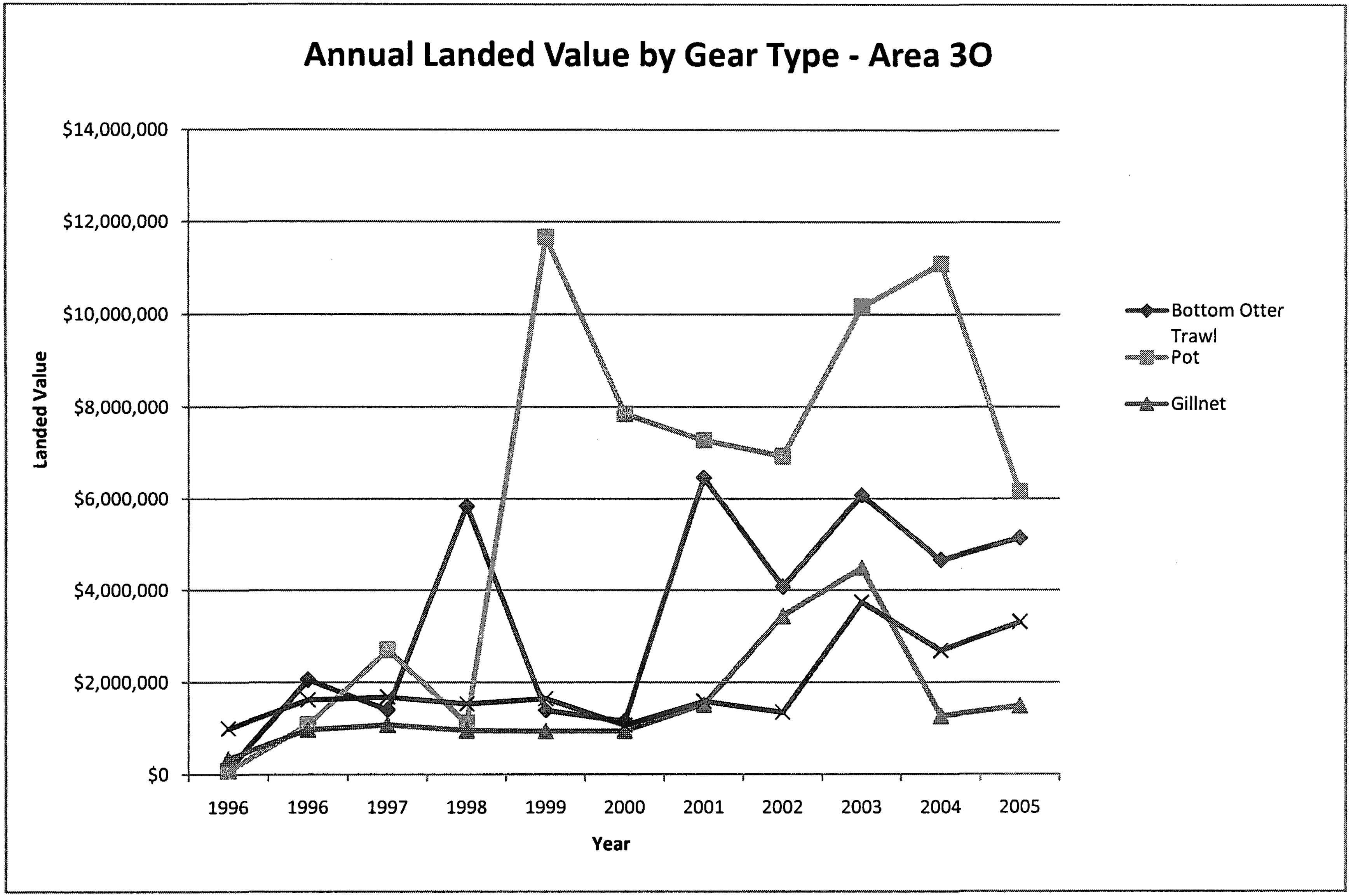

Figure A.4.14 Annual Landed Value by Gear Type - Area 3O. Bottom Otter Trawl, Pot, Gillnet, Longline. Years 1995-2005.

Table A.4.7 Annual Landed Weight by Species – Area 3L

Species	1995	1996	1997	1998	1999	2000
Cod	210,066	248,816	362,913	2,083,194	4,778,626	3,453,521
Redfish	3,513	235	19,648	496	475	31,568
Atlantic Halibut	1,518	4,311	123	30	7,131	92
American Plaice	55,760	31,198	10,925	12,004	12,055	163,687
Greenland Halibut	196,618	887,959	934,569	590,050	681,061	2,829,486
Monkfish	8,590	23,405	47	0	0	0
Lumpfish	197,396	224,047	217,432	106,109	384,407	342,834
Swordfish	68,325	81,187	40,084	0	0	0
Capelin	107,518	16,984,993	3,601,731	19,321,707	11,175,656	11,927,016
Clams	0	5,316	0	0	0	2,114
Cockles and Scallops	139,546	333,902	382,801	177,813	7,005	41,341
Lobster	185,844	175,656	138,404	146,083	158,339	125,614
Northern Shrimp	0	0	0	8,078	110,574	4,434,304
Snow Crab	14,006,857	16,472,244	20,691,159	23,292,985	26,241,558	22,631,759

Species	2001	2002	2003	2004	2005
Cod	3,592,279	2,971,712	953,899	456,868	674,799
Redfish	21,942	47,908	9,272	3,720	5,482
Atlantic Halibut	17,601	9,905	3,340	658	1,169
American Plaice	234,720	228,941	95,362	63,246	101,251
Greenland Halibut	2,666,711	1,464,844	959,971	810,530	1,379,346
Monkfish	0	7	2,748	0	0
Lumpfish	204,628	56,238	97,341	539,354	336,450
Swordfish	0	0	0	0	0
Capelin	13,795,715	8,655,176	13,270,135	15,693,887	14,741,042
Clams	42,661	0	0	1,837	0
Cockles and Scallops	6,572	0	0	2,003	4,901
Lobster	123,881	127,712	115,927	73,004	110,950
Northern Shrimp	5,053,087	5,402,266	10,784,857	10,312,284	11,439,288
Snow Crab	23,472,228	25,012,446	26,070,145	25,767,498	25,159,688

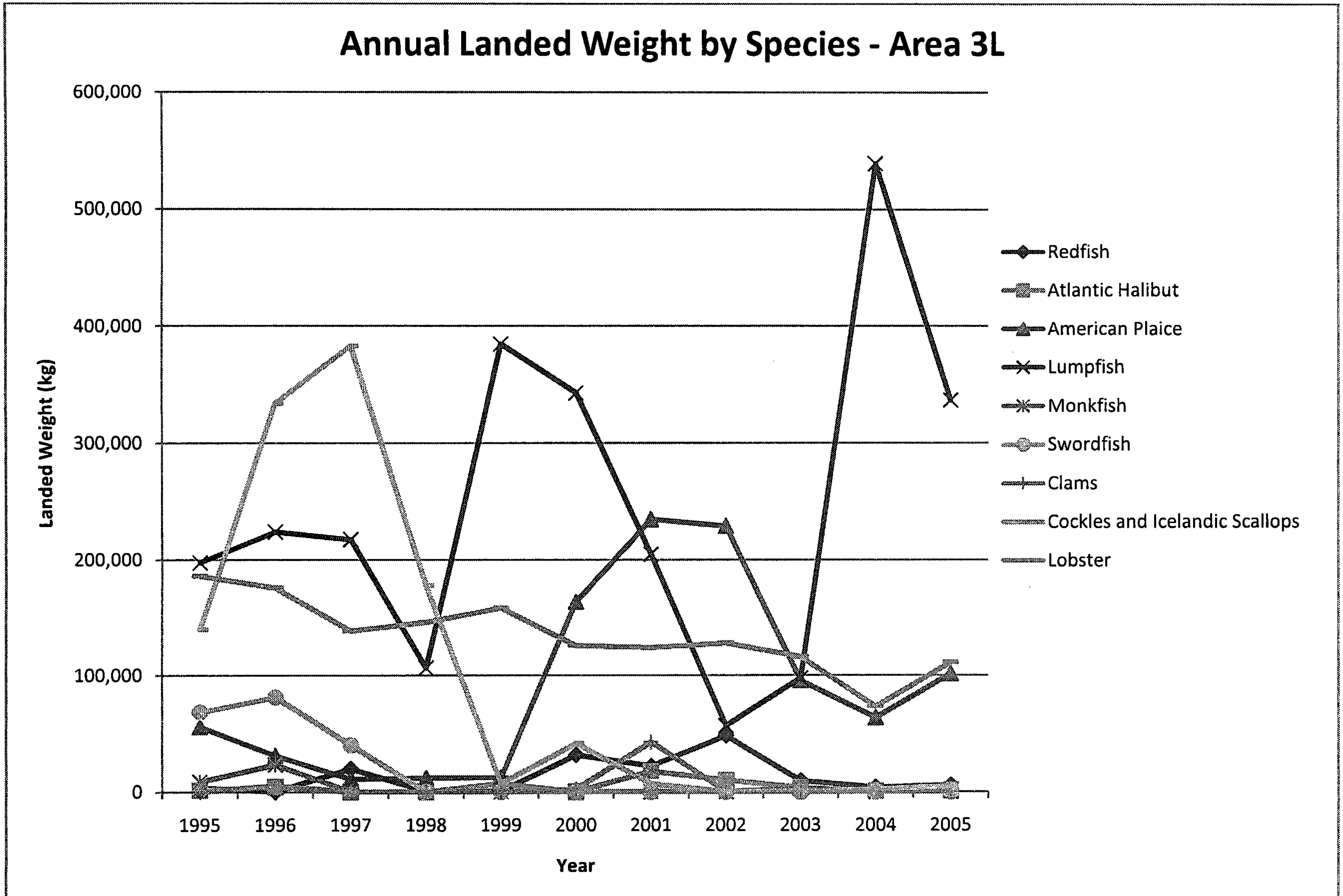

Figure A.4.15 Annual Landed Weight by Species – Area 3L. Cod, Greenland Halibut, Capelin, Northern Shrimp and Snow Crab Excluded. 1995-2005

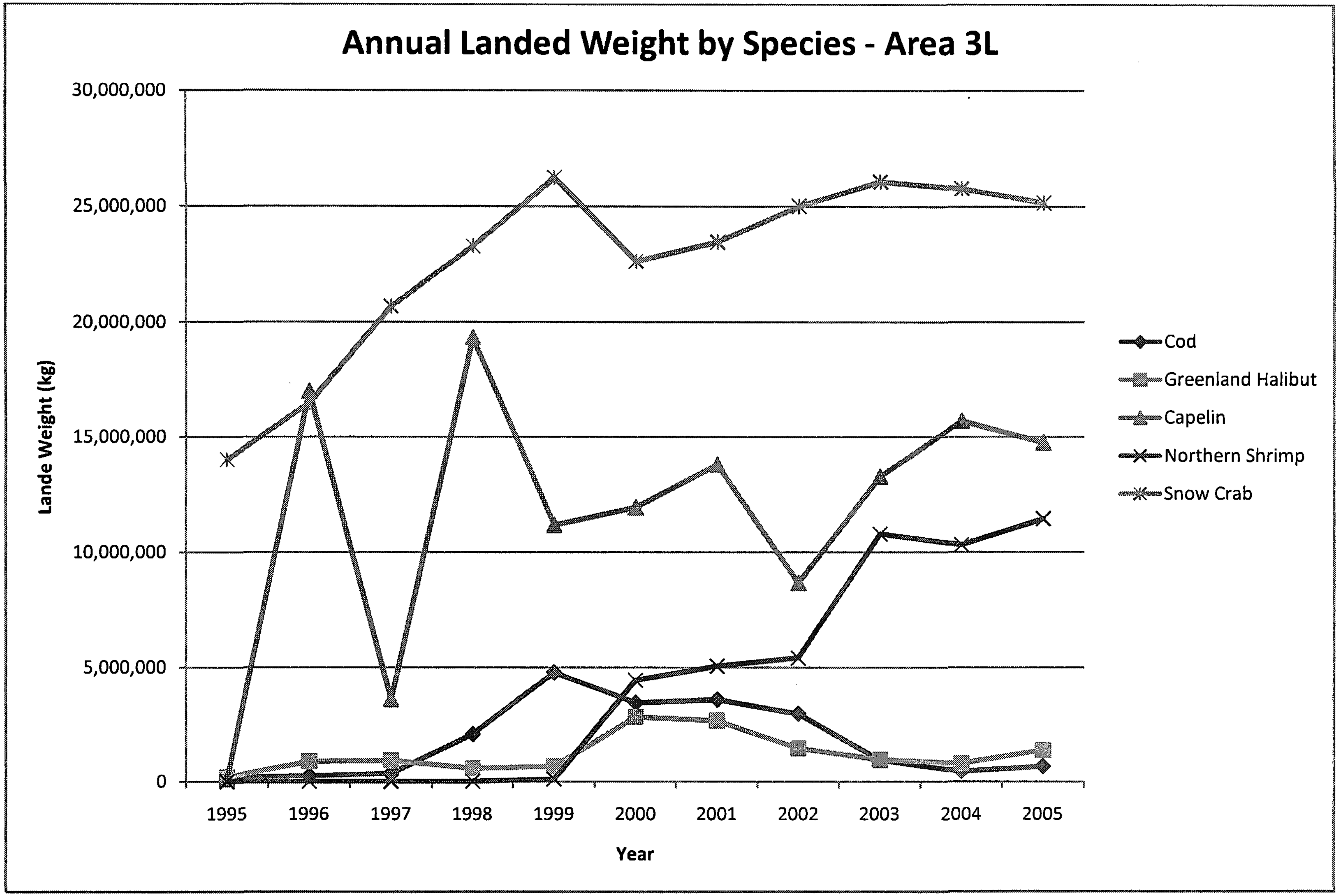

Figure A.4.16 Annual Landed Weight by Species – Area 3L. Cod, Greenland Halibut, Capelin, Northern Shrimp and Snow Crab. – 1995-2005

Table A.4.8 Annual Landed Weight by Species - Area 3N

Species	1995	1996	1997	1998	1999	2000
Cod	101	9,837	59,774	77,950	93,572	100,362
Redfish	0	0	1,324	6,759	4,896	0
Atlantic Halibut	4,744	6,389	24,960	20,465	37,152	96,423
American Plaice	118	1,774	12,750	133,458	259,195	413,930
Greenland Halibut	0	0	41	3,997	0	2,485
Monkfish	2,183	0	509	0	0	41
Lumpfish	0	0	0	0	0	0
Swordfish	0	1,731	50,036	62,533	180,963	52,800
Capelin	0	0	0	0	0	0
Clams	13,465,055	6,452,164	7,405,928	958,181	1,486,971	3,244,248
Cockles and Icelandic Scallops	7,039,689	9,501,807	3,570,741	1,121,262	133,508	294,554
Lobster	0	0	0	0	0	0
Northern Shrimp	0	0	0	0	0	17,145
Snow Crab	0	8,317	65,413	152,940	3,090,124	2,546,190

Species	2001	2002	2003	2004	2005
Cod	175,764	136,713	173,168	111,013	194,431
Redfish	18,212	0	0	0	1,759
Atlantic Halibut	72,155	15,671	37,319	21,469	48,608
American Plaice	854,256	838,729	923,089	748,122	1,003,738
Greenland Halibut	139	8	444	1,490	3,396
Monkfish	1,596	376	534	0	47
Lumpfish	0	0	0	0	0
Swordfish	96,548	40,130	22,594	27,942	23,086
Capelin	0	0	0	0	0
Clams	8,346,514	6,928,197	10,149,900	6,329,587	4,006,004
Cockles and Icelandic Scallops	31,603	0	3,240,358	4,428,572	6,730,739
Lobster	0	0	0	0	0
Northern Shrimp	0	0	0	0	1,818
Snow Crab	2,816,122	3,237,701	3,357,978	3,301,298	3,239,624

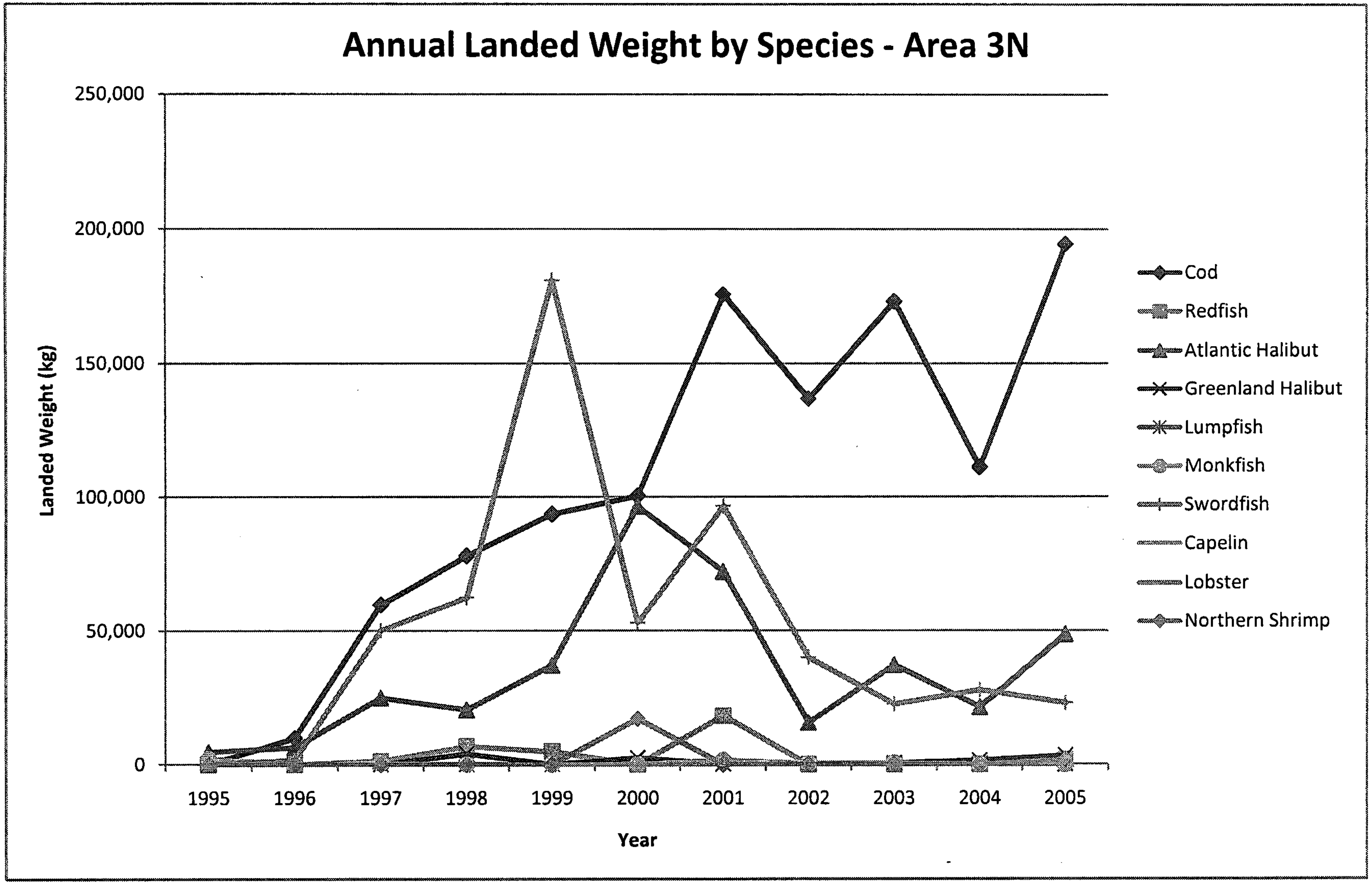

Figure A.4.17 Annual Landed Weight by Species – Area 3N. Cod, Redfish, Atlantic Halibut, Greenland Halibut, Lumpfish, Monkfish, Swordfish, Capelin, Lobster and Northern Shrimp. Years 1995 – 2005.

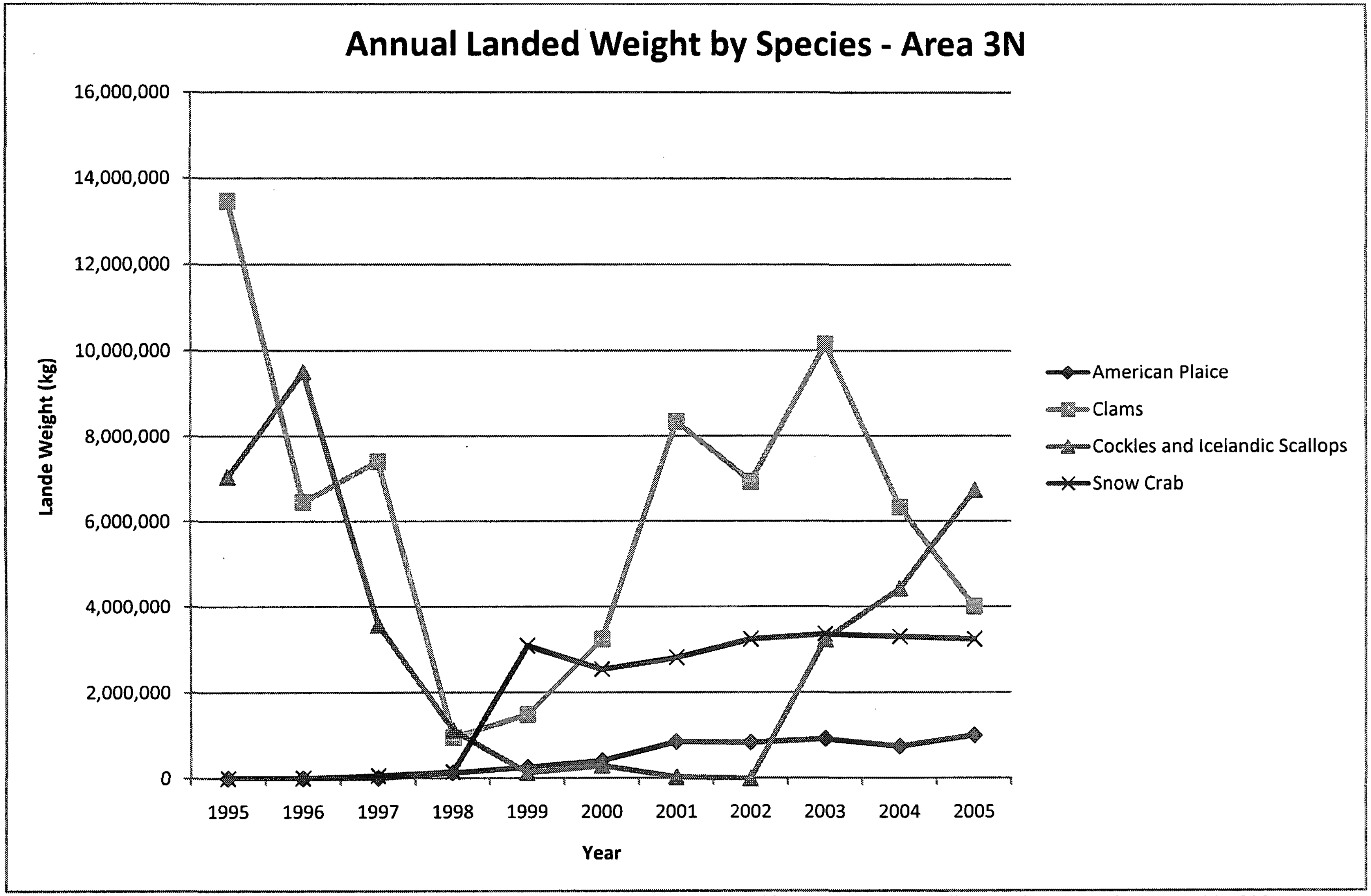

Figure A.4.18 Annual Landed Weight by Species – Area 3N. American Plaice, Clams, Cockles and Icelandic Scallops and Snow Crab. Years 1995-2005.

Table A.4.9 Annual Landed Weight by Species – Area 3O

Species	1995	1996	1997	1998	1999	2000
Cod	81,964	90,956	268,909	323,917	450,264	109,190
Redfish	176,279	7,088,983	2,554,525	8,821,907	2,343,498	2,206,456
Atlantic Halibut	77,494	104,978	177,813	141,167	82,685	71,726
American Plaice	11,416	16,138	50,977	89,199	52,729	40,687
Greenland Halibut	116,717	338,639	184,218	99,994	130,106	606,297
Monkfish	87,158	122,858	344,187	225,961	110,168	93,412
Lumpfish	0	0	0	0	0	0
Swordfish	51,236	125,968	130,401	134,724	186,131	113,876
Capelin	0	0	0	0	0	0
Clams	0	1,040	0	0	0	0
Cockles and Icelandic Scallops	168	0	33,722	2,105	0	0
Lobster	0	0	0	0	0	0
Northern Shrimp	0	4,305	0	0	0	0
Snow Crab	14,120	418,805	1,388,995	577,260	3,415,654	1,626,992

Species	2001	2002	2003	2004	2005
Cod	358,187	307,952	645,183	373,246	293,274
Redfish	4,892,411	3,000,237	3,125,258	2,617,182	5,499,746
Atlantic Halibut	162,699	187,787	220,106	102,370	128,945
American Plaice	439,727	248,284	586,637	484,738	363,624
Greenland Halibut	356,482	114,000	259,453	142,912	116,726
Monkfish	521,717	1,687,194	2,202,953	722,272	618,732
Lumpfish	0	0	0	0	0
Swordfish	115,928	82,276	234,163	249,955	316,204
Capelin	0	0	0	0	0
Clams	0	0	358	0	0
Cockles and Icelandic Scallops	0	0	0	0	17,206
Lobster	0	0	0	0	0
Northern Shrimp	0	0	0	0	0
Snow Crab	1,886,469	1,797,221	2,234,042	2,063,327	1,967,031

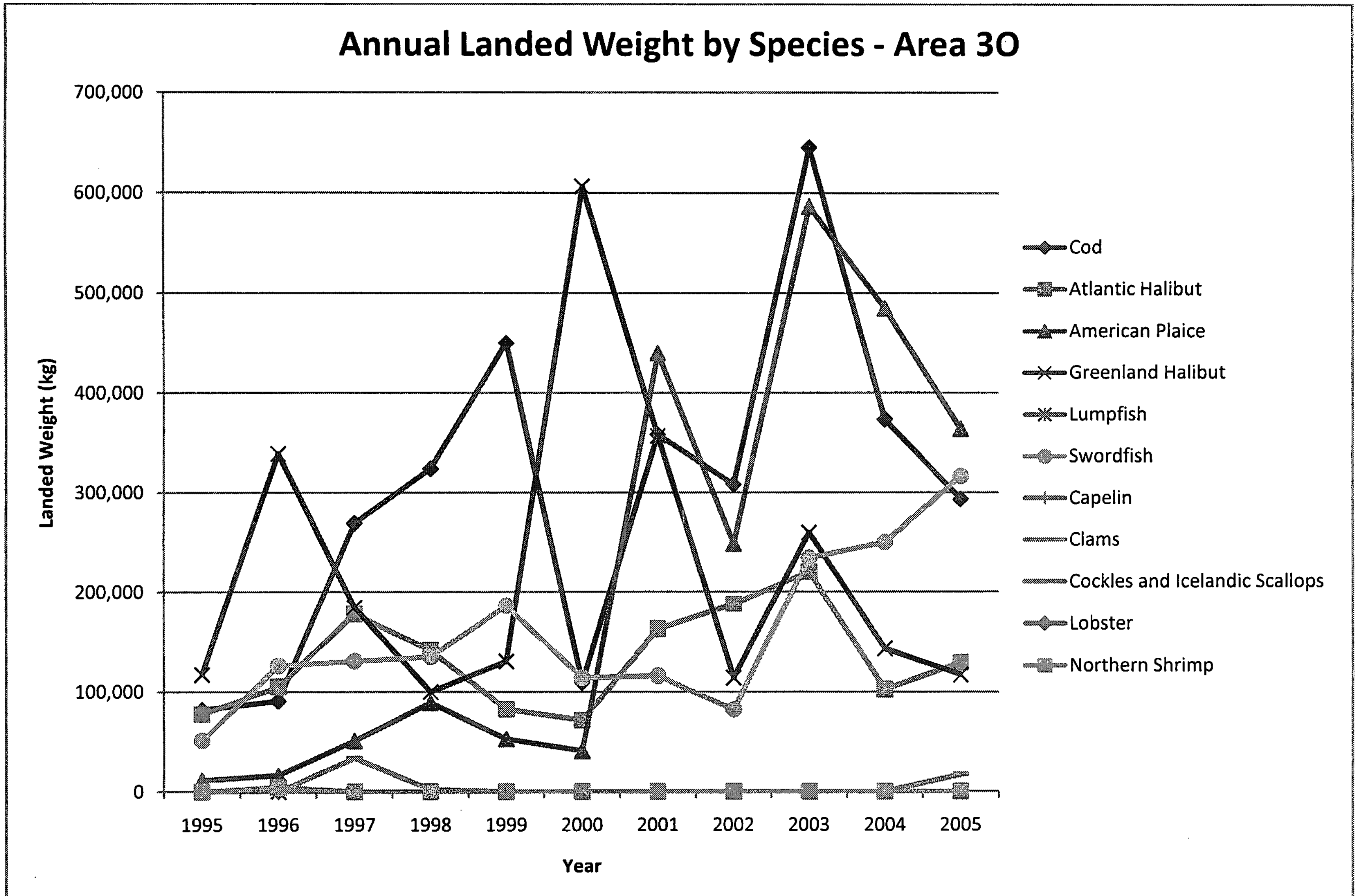

Figure A.4.19 Annual Landed Weight by Species – Area 3O. Excluding Redfish, Monkfish and Snow Crab. Years 1995-2005

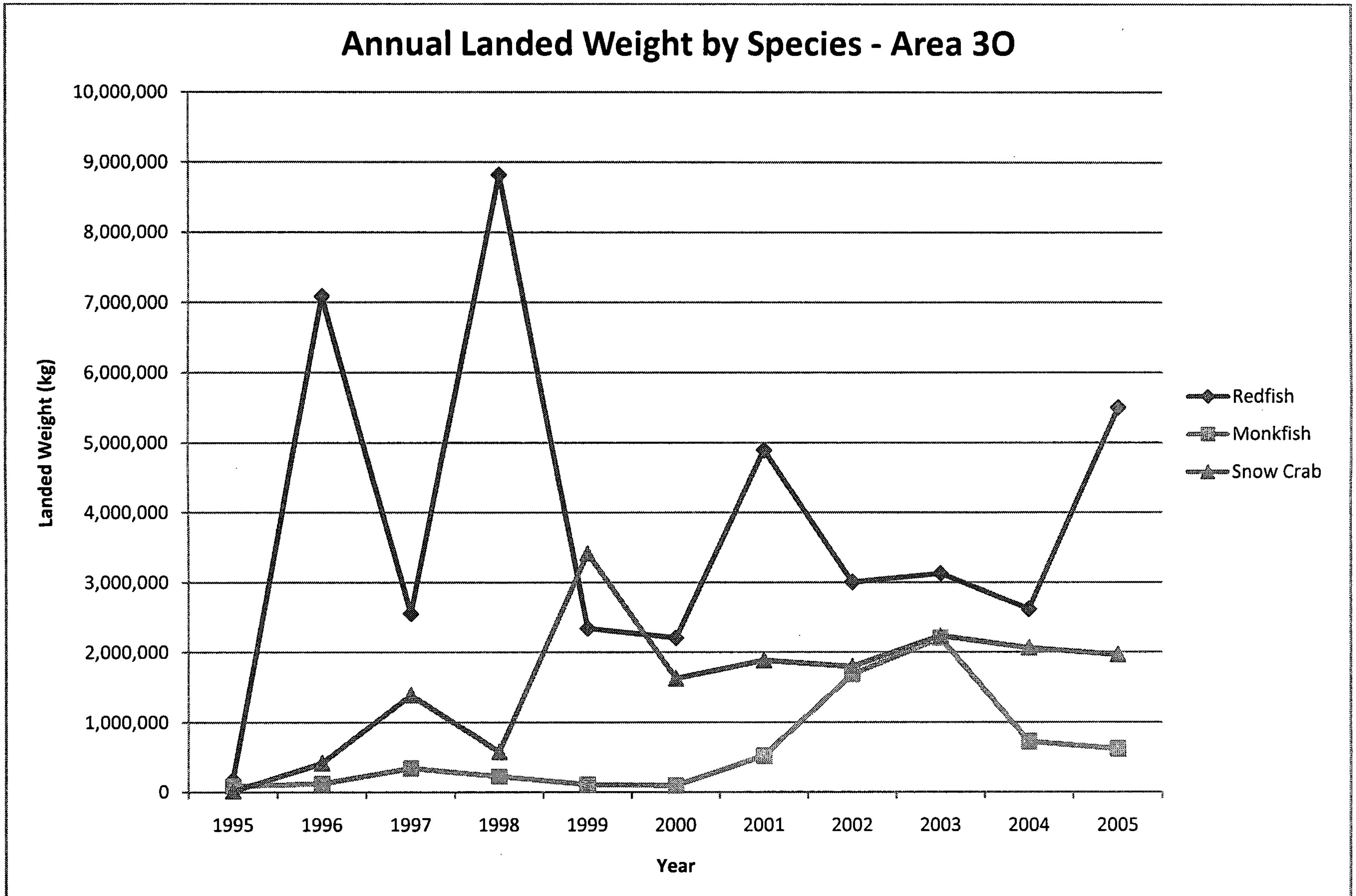

Figure A.4.20 Annual Landed Weight by Species – Area 3O. Redfish, Monkfish and Snow Crab. Years 1995-2005

Table A.4.10 Annual Landed Weight by Gear Type – Area 3L

Gear	1995	1996	1997	1998	1999
Bottom Otter Trawl	10,538	5,998	22,439	4,865	444
Midwater Trawl	0	0	0	0	0
Shrimp Trawl	0	0	0	8,078	110,574
Beach and Bar Seine	89,212	56,961	7,685	357,515	199,786
Purse Seine	0	7,605,028	3,460,546	9,299,714	7,236,265
Gillnet	618,238	1,360,039	1,436,821	2,036,726	5,409,718
Longline	93,277	100,880	62,777	277,040	69,947
Hand Line	7,874	14,207	24,526	446,093	356,129
Trap Net	29,735	9,343,118	172,776	9,694,644	3,770,210
Pot	14,193,342	16,647,900	20,829,563	23,439,068	26,399,897
Dredge	139,546	339,218	382,801	177,813	7,005

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	1,394,073	1,269,119	1,088,918	834,554	712,222
Midwater Trawl	0	0	0	0	0
Shrimp Trawl	5,053,087	5,402,274	10,784,857	10,312,284	11,439,288
Beach and Bar Seine	934,541	593,699	1,342,059	1,729,036	4,317,533
Purse Seine	7,084,145	5,412,049	6,157,391	6,718,463	6,597,091
Gillnet	4,779,970	3,009,914	287,931	1,338,950	2,267,751
Longline	122,396	46,307	4,514	7,905	1,021
Hand Line	456,737	355,798	783,745	53	0
Trap Net	5,950,014	2,776,499	5,770,685	7,246,388	3,826,418
Pot	23,596,109	25,140,158	26,186,072	25,840,502	25,329,705
Dredge	49,233	0	0	3,840	4,901

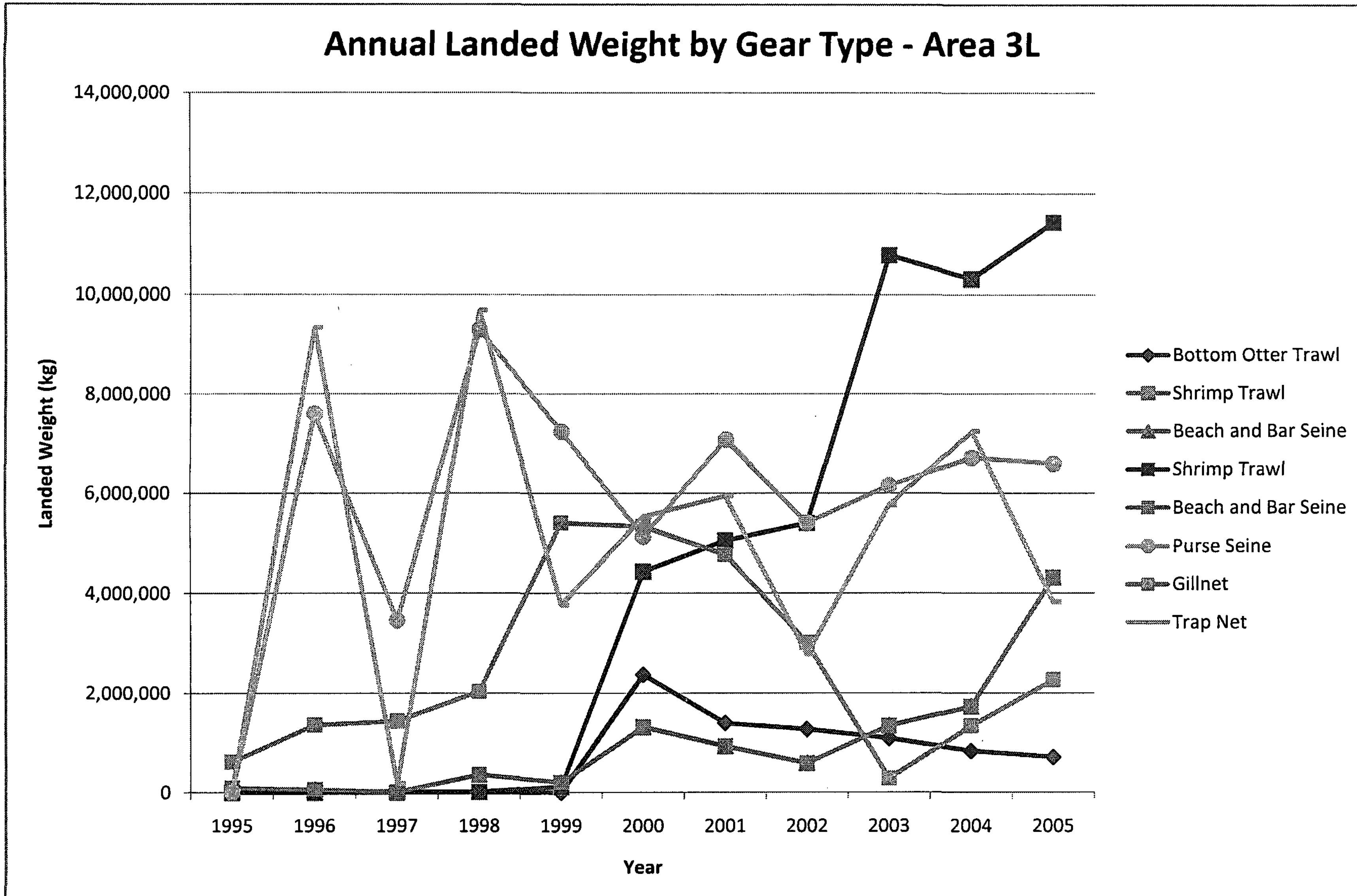

Figure A.4.21 Annual Landed Weight by Gear Type – Area 3L Excluding Midwater Trawl, Longline, Hand Line, Dredge and Pot. Years 1995-2005.

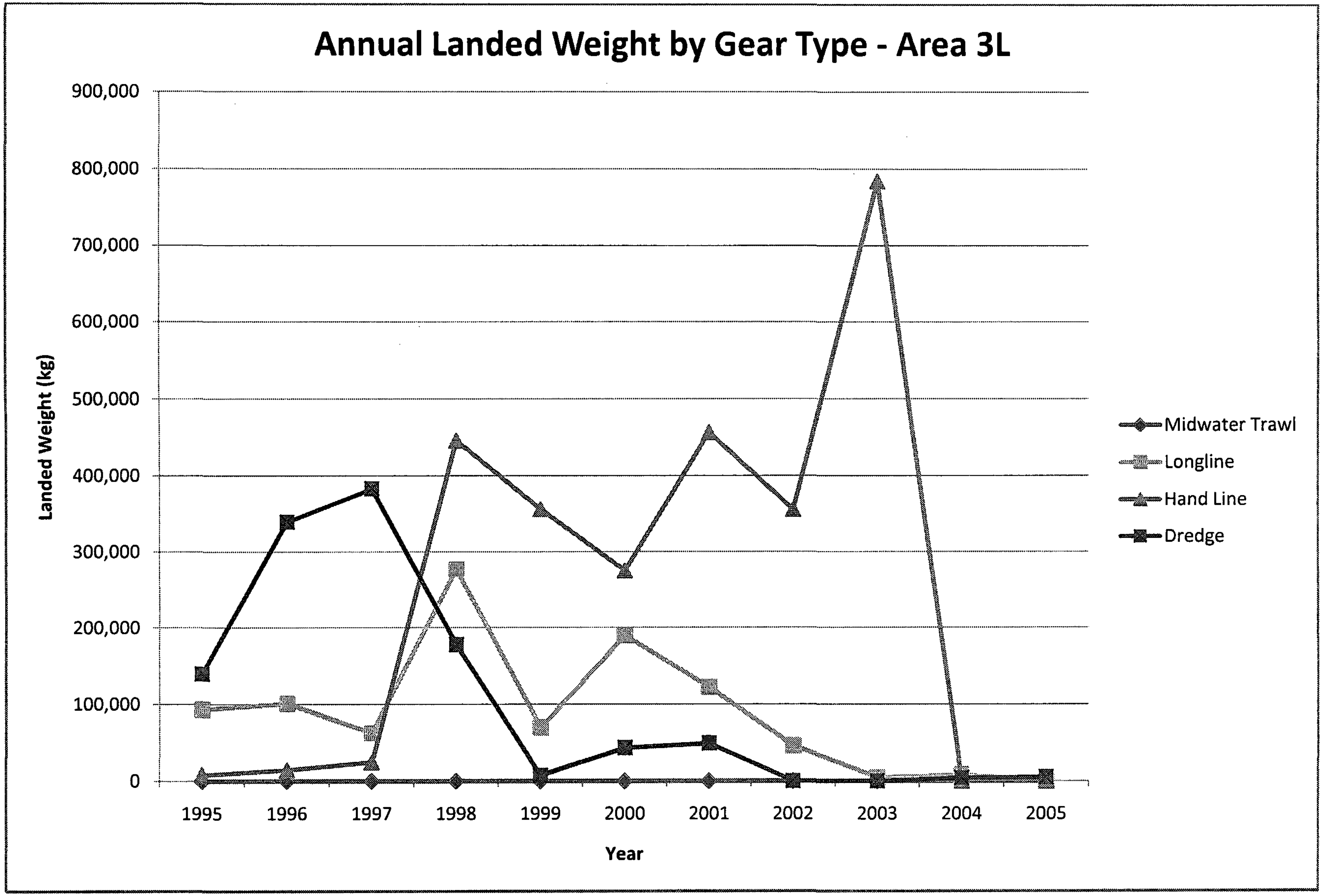

Figure A.4.22 Annual Landed Weight by Gear Type - Area 3L. Midwater Trawl, Longline, Hand Line, Dredge Years 1995-2005.

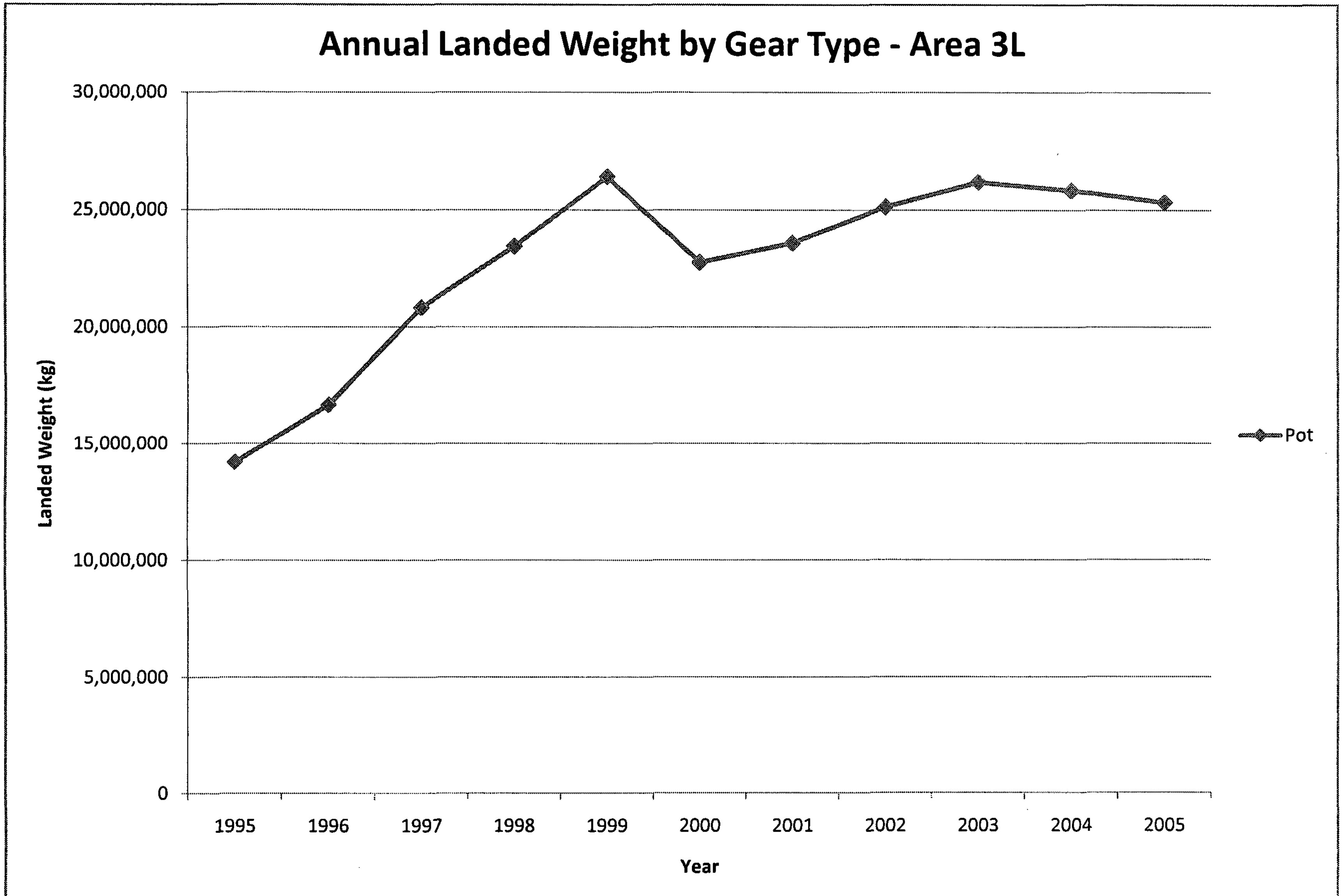

Figure A.4.23 Annual Landed Weight by Gear Type - Area 3L. Pot. Years 1995-2005.

Table A.4.11 Annual Landed Weight by Gear Type – Area 3N

Gear	1995	1996	1997	1998	1999	2000
Bottom Otter Trawl	57	0	2,356	3,179,537	1,369,616	8,237,597
Midwater Trawl	0	0	0	0	4,582,927	0
Shrimp Trawl	0	0	0	0	0	17,145
Beach and Bar Seine	0	0	0	0	0	0
Purse Seine	0	0	0	0	0	0
Gillnet	3,575	1,839	69,799	0	18,151	1,117
Longline	3,514	17,897	77,937	89,354	240,222	163,646
Hand Line	0	0	0	0	0	0
Trap Net	0	0	0	0	0	0
Pot	0	8,317	65,413	152,940	3,090,124	2,546,190
Dredge	20,504,744	15,953,971	10,976,669	2,079,443	1,620,479	3,538,802

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	9,742,322	8,692,654	9,286,989	9,681,099	11,851,152
Midwater Trawl	0	0	0	0	0
Shrimp Trawl	0	0	0	0	1,818
Beach and Bar Seine	0	0	0	0	0
Purse Seine	0	0	0	0	0
Gillnet	1,101	0	0	0	3,376
Longline	175,542	45,941	60,848	57,439	86,604
Hand Line	0	0	0	0	0
Trap Net	0	0	0	0	0
Pot	2,816,122	3,237,701	3,357,978	3,301,298	3,239,624
Dredge	8,378,117	6,928,197	13,390,258	10,758,159	10,736,743

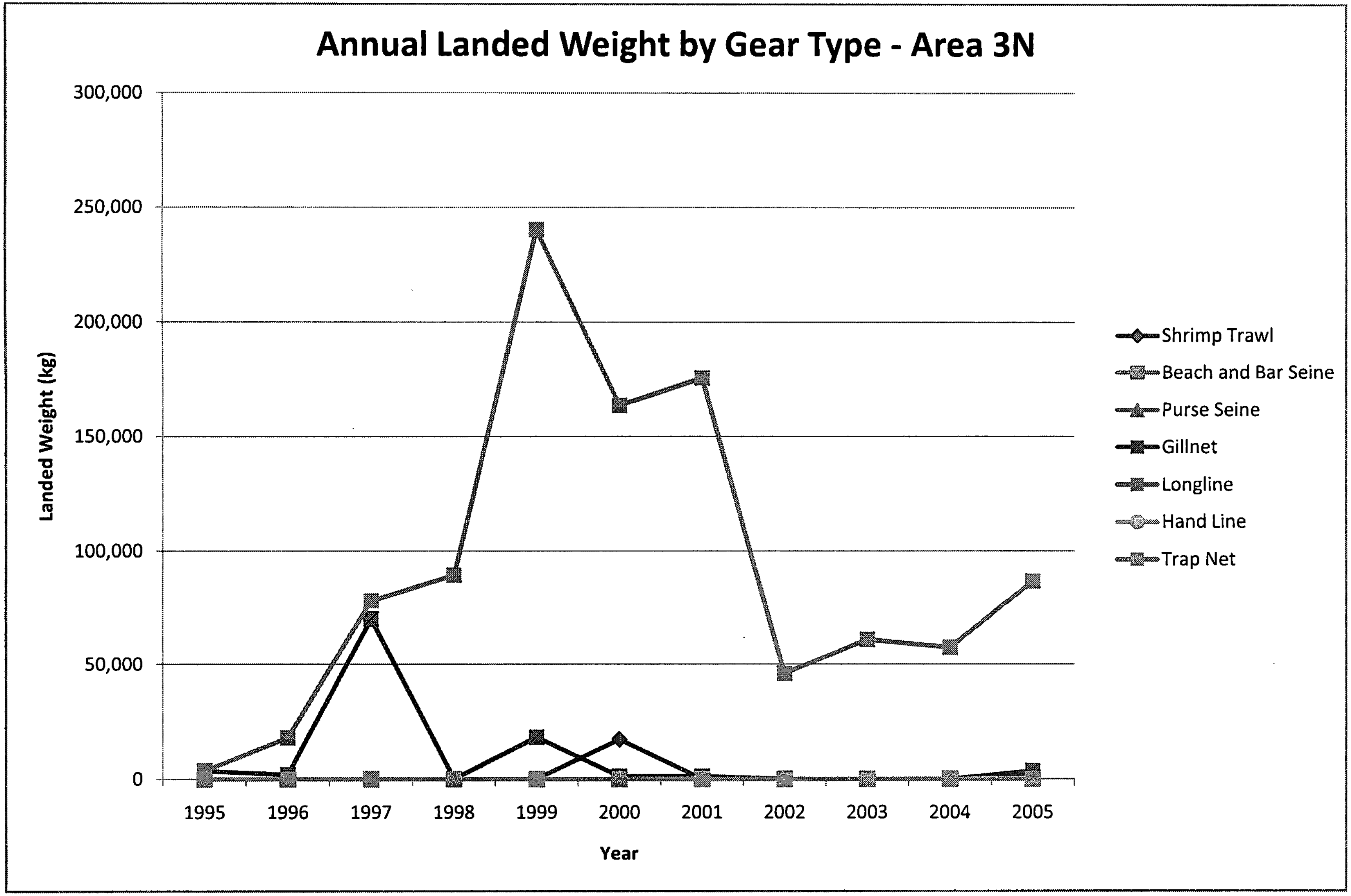

Figure A.4.24 Annual Landed Weight by Gear Type - Area 3N. Shrimp Trawl, Beach and Bar Seine, Purse Seine, Gillnet, Longline, Hand Line and Trap Net. Years 1995-2005.

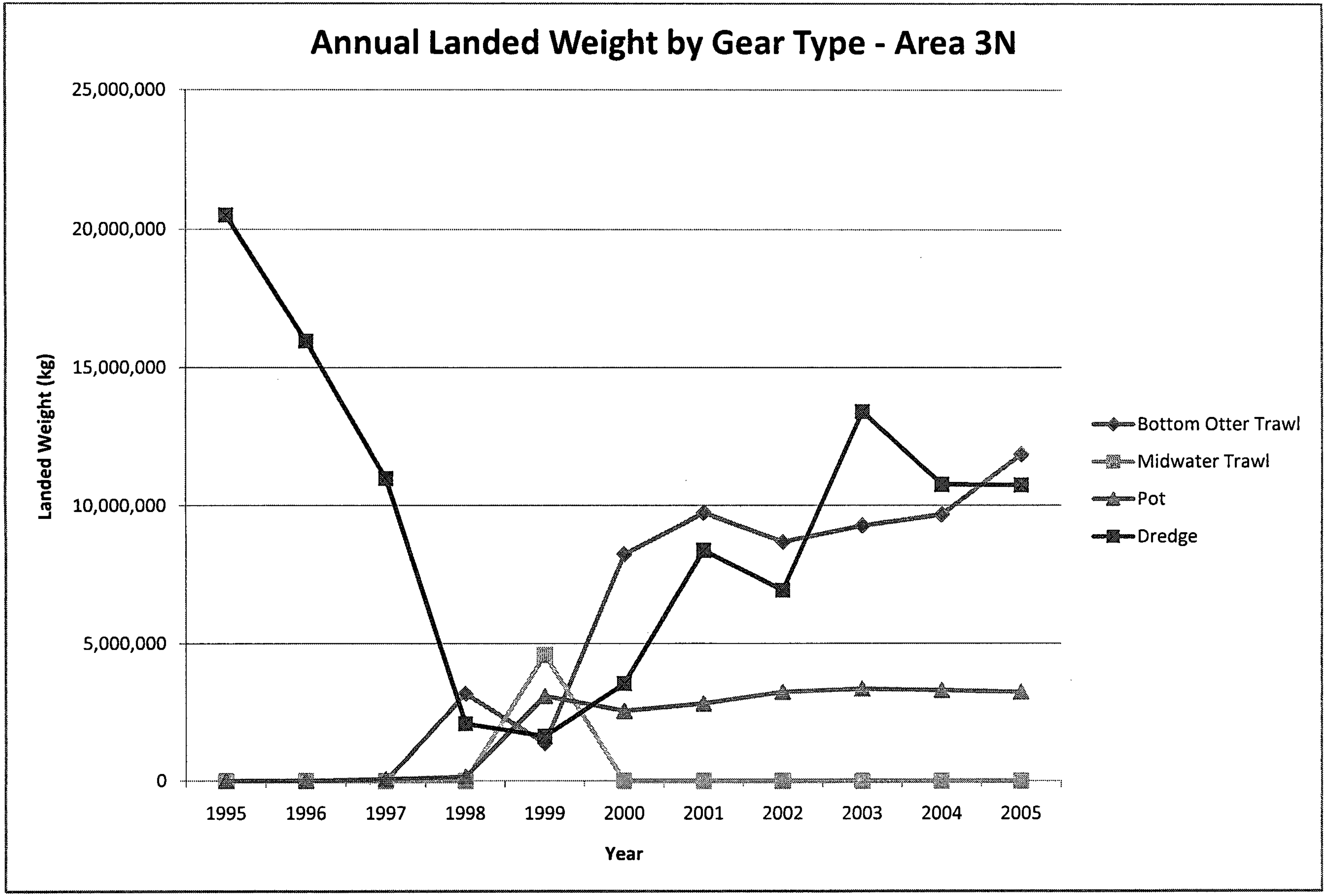

Figure A.4.25 Annual Landed Weight by Gear Type - Area 3N. Bottom Otter Trawl, Midwater Trawl, Pot and Dredge. Years 1995 to 2005.

Table A.4.12 Annual Landed Weight by Gear Type – Area 3O

Gear	1995	1996	1997	1998	1999	2000
Bottom Otter Trawl	122,248	6,803,863	2,715,762	9,797,052	2,217,855	2,520,084
Midwater Trawl	107,754	335,342	13,379	0	365,718	41,734
Shrimp Trawl	0	4,305	0	0	0	0
Beach and Bar Seine	0	0	0	0	0	0
Purse Seine	0	0	0	0	0	0
Gillnet	188,208	507,730	725,563	487,150	586,694	772,182
Longline	186,140	241,611	256,326	298,303	291,937	186,886
Hand Line	0	0	0	0	0	0
Trap Net	0	0	0	0	0	0
Pot	14,120	418,805	1,388,995	577,260	3,415,654	1,626,992
Dredge	168	1,040	33,722	2,105	0	0

Gear	2001	2002	2003	2004	2005
Bottom Otter Trawl	8,737,783	5,532,876	8,711,458	6,888,807	8,246,626
Midwater Trawl	0	0	0	0	0
Shrimp Trawl	0	0	0	0	0
Beach and Bar Seine	0	0	0	0	0
Purse Seine	0	0	0	0	0
Gillnet	897,423	1,888,546	2,600,908	1,038,326	751,441
Longline	327,636	238,698	1,009,325	487,615	457,849
Hand Line	0	0	0	0	0
Trap Net	0	0	0	0	0
Pot	1,886,469	1,797,221	2,234,042	2,063,327	1,967,031
Dredge	0	0	358	0	17,206

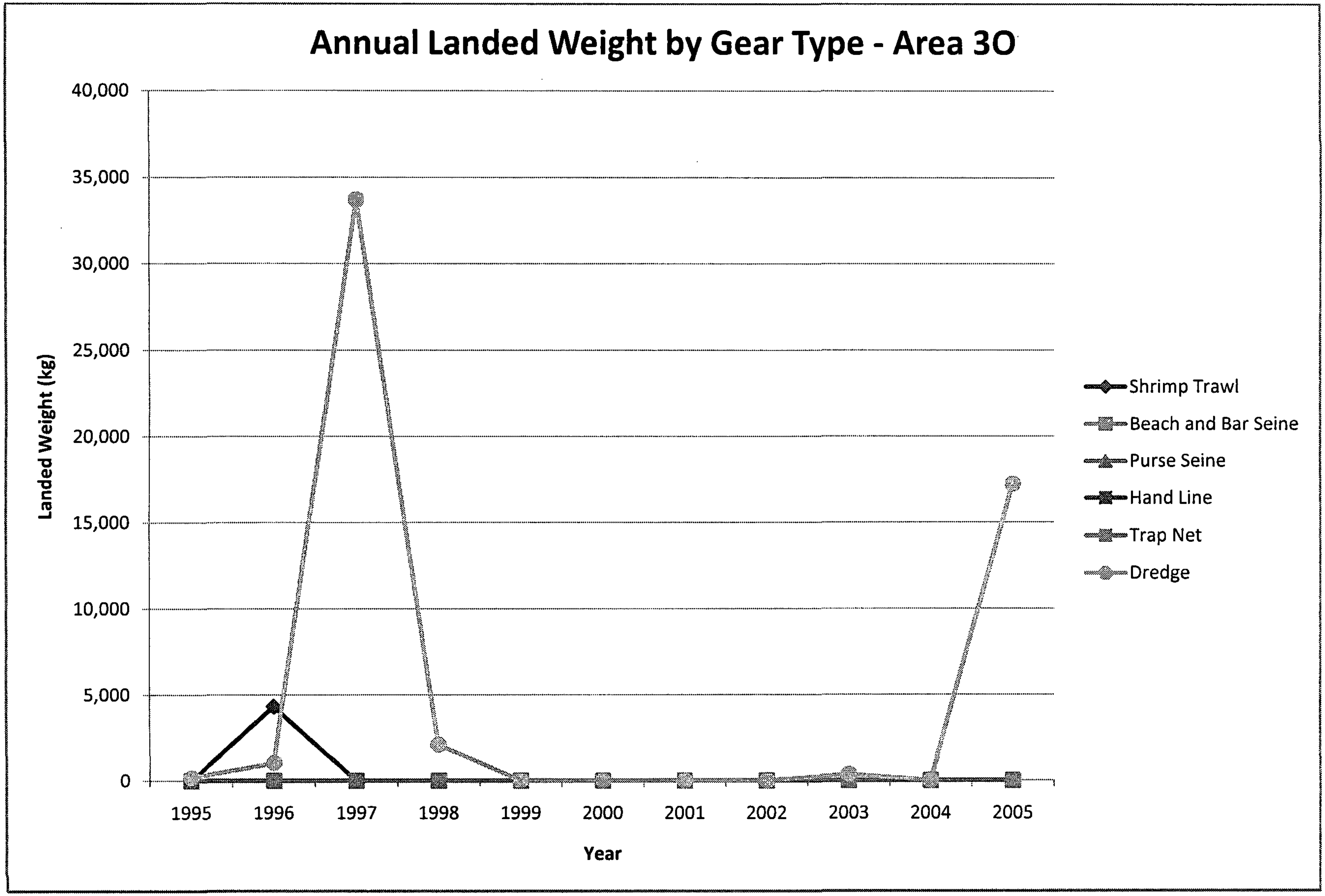

Figure A.4.26 Annual Landed Weight by Gear Type - Area 3O. Shrimp Trawl, Beach and Bar Seine, Purse Seine, Hand Line and Trap Net. Years 1995 to 2005.

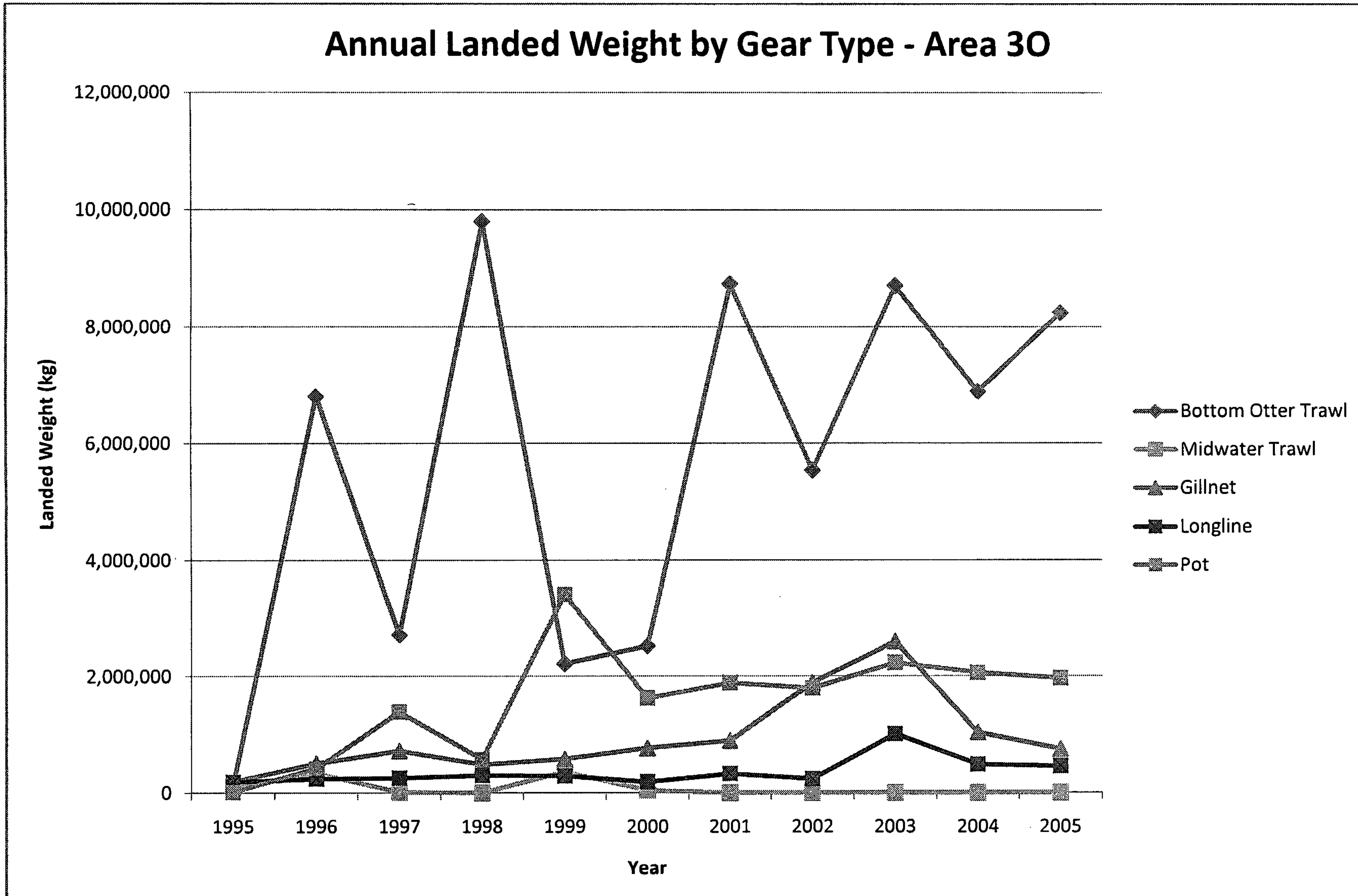

Figure A.4.27 Annual Landed Weight by Gear Type – Area 30. Bottom Otter Trawl, Midwater Trawl, Gillnet, Longline and Pot. Years 1995 to 2005.

Table A.4.13 Annual Landed Price per kg - Area 3L. Years 1995-2005

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$0.91	$0.94	$0.93	$1.58	$1.38	$1.42	$1.35	$1.27	$1.29	$1.16	$1.07
Redfish	$0.28	$2.38	$1.45	$0.65	$0.55	$0.57	$0.66	$0.64	$0.56	$0.53	$0.53
Atlantic Halibut	$5.15	$5.92	$5.47	$5.58	$5.05	$5.29	$6.96	$5.76	$6.60	$6.54	$6.55
American Plaice	$0.87	$1.08	$1.19	$0.81	$0.82	$0.80	$0.77	$0.80	$0.76	$0.77	$0.66
Greenland Halibut	$2.17	$1.85	$0.98	$1.58	$1.14	$0.99	$0.93	$1.02	$1.84	$1.87	$2.00
Monkfish	$1.14	$1.84	$1.30					$1.67	$1.65		
Lumpfish	$6.60	$6.61	$4.44	$2.20	$2.43	$2.20	$4.64	$6.33	$5.75	$5.40	$3.12
Swordfish	$8.56	$7.22	$6.78								
Capelin	$0.34	$0.17	$0.42	$0.23	$0.16	$0.17	$0.15	$0.13	$0.16	$0.25	$0.28
Clams		$0.93				$0.89	$0.80			$1.36	
Cockles and Scallops	$1.44	$1.47	$1.60	$1.59	$1.50	$1.47	$1.47			$1.05	$1.55
Lobster	$9.82	$9.31	$10.59	$9.46	$10.29	$11.47	$12.11	$11.80	$11.55	$11.47	$12.17
Northern Shrimp				$1.34	$3.09	$1.66	$1.91	$1.82	$1.55	$1.33	$1.40
Snow Crab	$5.34	$2.54	$1.96	$1.94	$3.42	$4.83	$3.86	$3.86	$4.52	$5.42	$3.19

Table A.4.14 Annual Landed Price per kg – Area 3N. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.48	$1.44	$1.12	$1.58	$1.40	$1.36	$1.39	$1.39	$1.32	$1.29	$1.15
Redfish			$0.77	$0.60	$0.60		$0.66				$0.52
Atlantic Halibut	$7.64	$5.36	$6.98	$7.26	$8.06	$7.50	$7.64	$5.74	$8.23	$8.33	$8.81
American Plaice	$0.77	$0.83	$0.75	$0.81	$0.81	$0.80	$0.80	$0.80	$0.77	$0.79	$0.66
Greenland Halibut			$1.10	$1.54		$0.99	$0.83	$1.08	$1.70	$1.81	$1.92
Monkfish	$2.02		$1.28			$1.64	$1.65	$1.68	$1.69		$1.67
Lumpfish											
Swordfish		$8.59	$6.41	$5.88	$5.77	$6.29	$6.31	$6.96	$0.00	$7.56	$8.28
Capelin											
Clams	$1.12	$0.93	$0.81	$0.80	$0.78	$0.89	$0.82	$0.77	$1.22	$1.18	$1.06
Cockles and Scallops	$1.36	$1.50	$1.60	$1.59	$1.50	$1.46	$1.46		$1.24	$0.84	$0.85
Lobster											
Northern Shrimp						$1.28					$1.15
Snow Crab		$2.57	$1.96	$1.94	$3.42	$4.83	$3.86	$3.86	$4.55	$5.42	$3.19

Table A.4.15 Annual Landed Price per kg – Area 3O. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.43	$1.26	$1.13	$1.53	$1.38	$1.38	$1.40	$1.37	$1.36	$1.27	$1.08
Redfish	$0.32	$0.29	$0.47	$0.56	$0.59	$0.39	$0.64	$0.62	$0.57	$0.46	$0.52
Atlantic Halibut	$7.07	$6.02	$6.07	$6.22	$5.78	$6.27	$6.13	$6.15	$7.10	$7.07	$7.42
American Plaice	$0.92	$0.88	$0.69	$0.78	$0.80	$0.80	$0.80	$0.81	$0.76	$0.79	$0.66
Greenland Halibut	$1.53	$1.82	$1.20	$1.55	$1.14	$0.84	$1.09	$1.23	$2.13	$2.10	$2.36
Monkfish	$1.47	$1.49	$0.95	$1.49	$1.52	$1.65	$1.64	$1.65	$1.61	$1.07	$1.60
Lumpfish											
Swordfish	$8.72	$8.80	$7.81	$6.52	$7.18	$7.14	$7.06	$8.08	$9.24	$8.36	$8.32
Capelin											
Clams		$0.84							$0.81		
Cockles and Icelandic Scallops	$1.33		$1.63	$1.59							$2.10
Lobster											
Northern Shrimp		$1.98									
Snow Crab	$5.51	$2.60	$1.95	$1.94	$3.42	$4.83	$3.86	$3.86	$4.55	$5.38	$3.13

Table A.4.16 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3L. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.10	$1.13	$1.10	$1.85	$1.59	$1.59	$1.47	$1.36	$1.35	$1.18	$1.07
Redfish	$0.34	$2.86	$1.72	$0.76	$0.64	$0.64	$0.72	$0.68	$0.59	$0.54	$0.53
Atlantic Halibut	$6.28	$7.11	$6.46	$6.53	$5.81	$5.92	$7.54	$6.16	$6.89	$6.65	$6.55
American Plaice	$1.06	$1.29	$1.40	$0.95	$0.94	$0.90	$0.83	$0.86	$0.80	$0.78	$0.66
Greenland Halibut	$2.64	$2.22	$1.16	$1.85	$1.32	$1.11	$1.01	$1.09	$1.92	$1.90	$2.00
Monkfish	$1.39	$2.20	$1.53					$1.79	$1.72		
Lumpfish	$8.05	$7.94	$5.24	$2.58	$2.79	$2.47	$5.02	$6.77	$6.00	$5.49	$3.12
Swordfish	$10.43	$8.67	$8.01								
Capelin	$0.42	$0.21	$0.49	$0.27	$0.19	$0.19	$0.16	$0.14	$0.16	$0.26	$0.28
Clams		$1.11				$1.00	$0.87			$1.38	
Cockles and Icelandic Scallops	$1.76	$1.76	$1.89	$1.86	$1.72	$1.65	$1.59			$1.07	$1.55
Lobster	$11.97	$11.19	$12.51	$11.06	$11.84	$12.84	$13.11	$12.63	$12.04	$11.67	$12.17
Northern Shrimp				$1.57	$3.56	$1.86	$2.07	$1.95	$1.62	$1.35	$1.40
Snow Crab	$6.51	$3.05	$2.32	$2.27	$3.93	$5.40	$4.18	$4.13	$4.71	$5.51	$3.19

Table A.4.17 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3N. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.80	$1.73	$1.33	$1.85	$1.61	$1.53	$1.50	$1.48	$1.37	$1.31	$1.15
Redfish			$0.91	$0.70	$0.69		$0.72				$0.52
Atlantic Halibut	$9.32	$6.44	$8.25	$8.49	$9.28	$8.39	$8.27	$6.15	$8.58	$8.47	$8.81
American Plaice	$0.94	$0.99	$0.88	$0.94	$0.93	$0.90	$0.87	$0.86	$0.80	$0.80	$0.66
Greenland Halibut			$1.30	$1.80		$1.10	$0.90	$1.15	$1.78	$1.84	$1.92
Monkfish	$2.46		$1.51			$1.83	$1.79	$1.79	$1.77		$1.67
Lumpfish											
Swordfish		$10.32	$7.57	$6.88	$6.64	$7.04	$6.83	$7.45		$7.69	$8.28
Capelin											
Clams	$1.37	$1.12	$0.96	$0.94	$0.90	$1.00	$0.88	$0.82	$1.27	$1.20	$1.06
Cockles and Icelandic Scallops	$1.66	$1.80	$1.89	$1.86	$1.72	$1.63	$1.58		$1.29	$0.85	$0.85
Lobster											
Northern Shrimp						$1.43					$1.15
Snow Crab		$3.09	$2.32	$2.27	$3.93	$5.40	$4.18	$4.13	$4.74	$5.51	$3.19

Table A.4.18 Annual Landed Price per kg Corrected for Inflation, 2005 Dollars – Area 3O. Years 1995-2005.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cod	$1.75	$1.51	$1.34	$1.79	$1.59	$1.54	$1.52	$1.46	$1.41	$1.29	$1.08
Redfish	$0.39	$0.34	$0.55	$0.65	$0.68	$0.44	$0.70	$0.66	$0.60	$0.47	$0.52
Atlantic Halibut	$8.62	$7.23	$7.17	$7.28	$6.65	$7.02	$6.64	$6.58	$7.40	$7.19	$7.42
American Plaice	$1.12	$1.05	$0.82	$0.92	$0.93	$0.90	$0.87	$0.86	$0.80	$0.80	$0.66
Greenland Halibut	$1.87	$2.19	$1.41	$1.81	$1.32	$0.94	$1.18	$1.31	$2.22	$2.14	$2.36
Monkfish	$1.79	$1.79	$1.12	$1.74	$1.74	$1.85	$1.78	$1.77	$1.68	$1.09	$1.60
Lumpfish											
Swordfish	$10.63	$10.57	$9.23	$7.62	$8.26	$7.99	$7.64	$8.64	$9.64	$8.50	$8.32
Capelin											
Clams		$1.01							$0.85		
Cockles and Icelandic Scallops	$1.63		$1.93	$1.86							$2.10
Lobster											
Northern Shrimp		$2.38									
Snow Crab	$6.72	$3.12	$2.30	$2.27	$3.93	$5.40	$4.18	$4.13	$4.75	$5.48	$3.13

A.5 Time Analysis

In order to characterize the seasonal dynamics of the commercial fisheries on the Grand Banks, it is necessary to perform an in-season time period (weekly) analysis. The following graphs show the weekly landings by gear type for the years 1995 to 2005, according to catch date.

- Catches by Bottom OtterTrawl show a clear trend of two seasons of high catches from week 13 to week 23 and from week 35 to 48, with lower catches outside of these periods.
- The main season of shrimp trawl catches begins on week 21 and ends on week 32 with a peak on week 24. A second peak occurs on weeks 37 to 41 and a third at the beginning of the year through to week 6.
- Beach and Bar Seine, Purse Seine and Trap Net catches show all of their activity concentrated on a few weeks, with Beach and Bar Seine activity occurring on weeks 28 to 31, weeks 27 to 30 for Purse Seine and weeks 29 to 31 for Trap Net. Beach and Bar Seine activity is concentrated on weeks 28 to 31. Purse Seine 27 to 30, Trap Net 29 to 31. We can hypothesize that all three are used to prosecute the same species.
- The use of Gillnet is more spread out through the year with the main catches taking place from week 19 to week 41, characterized by a steady increase to a peak on week 26 then two dips on weeks 27 and 37.
- Regarding Longline, there is activity throughout the year, with a main season from week 29 to 43 that includes a first peak on week 34 and a second on week 39. There also is a secondary period of increased activity from week 16 to 19.
- Handline is actively used from week 36 to week 42, except for single-year peak from week 14 to week 17.The use of the gear type Pot shows no activity until week 15, then a steady increase to week 20, remaining high to week 25, a decrease to a low level by week 35 and going to nil by the end of the year.
- Dredge activity is seen throughout the year except for a marked dip on week 10 and a decrease from week 47 to the end of the year.

- There is no visible pattern in Midwater Trawl catches, an issue which will be addressed in section A.7.1.

We can conclude that patterns of weekly catches are comparable from year to year and show clear seasonality in the activity of fishing vessels. In this and in the previous sections we established the seasonality and the spatial dimension of the catch, respectively. In order to further characterize the dynamics of the Grand Banks fishing fleet we establish, in the next section, which combinations of species and gear types are significant. The spatial and time components of the analysis can then be further refined by taking into account these combinations.

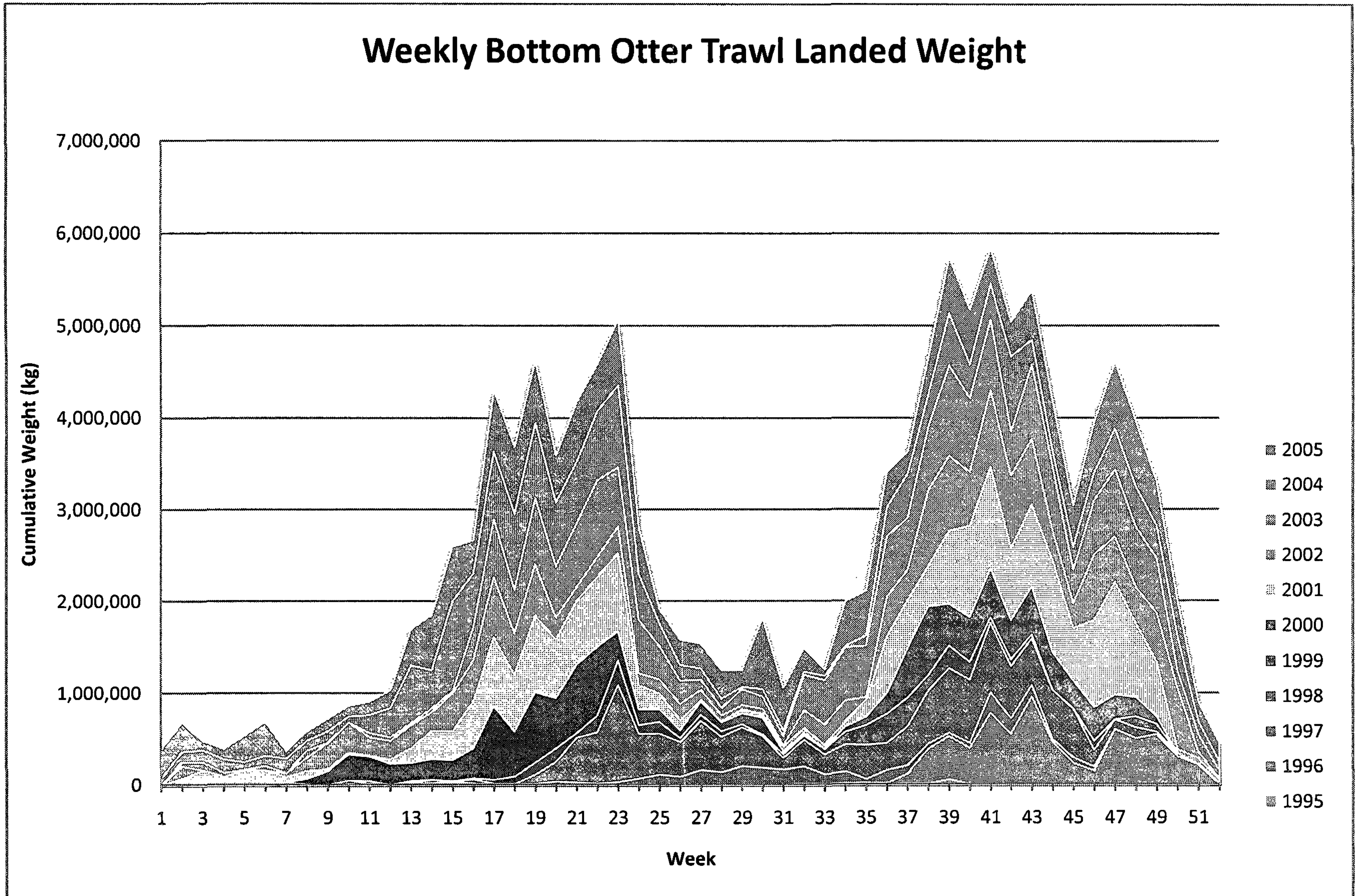

Figure A.5.1Cumulative Weekly Bottom Otter Trawl Landed Weight. Years 1995-2005.

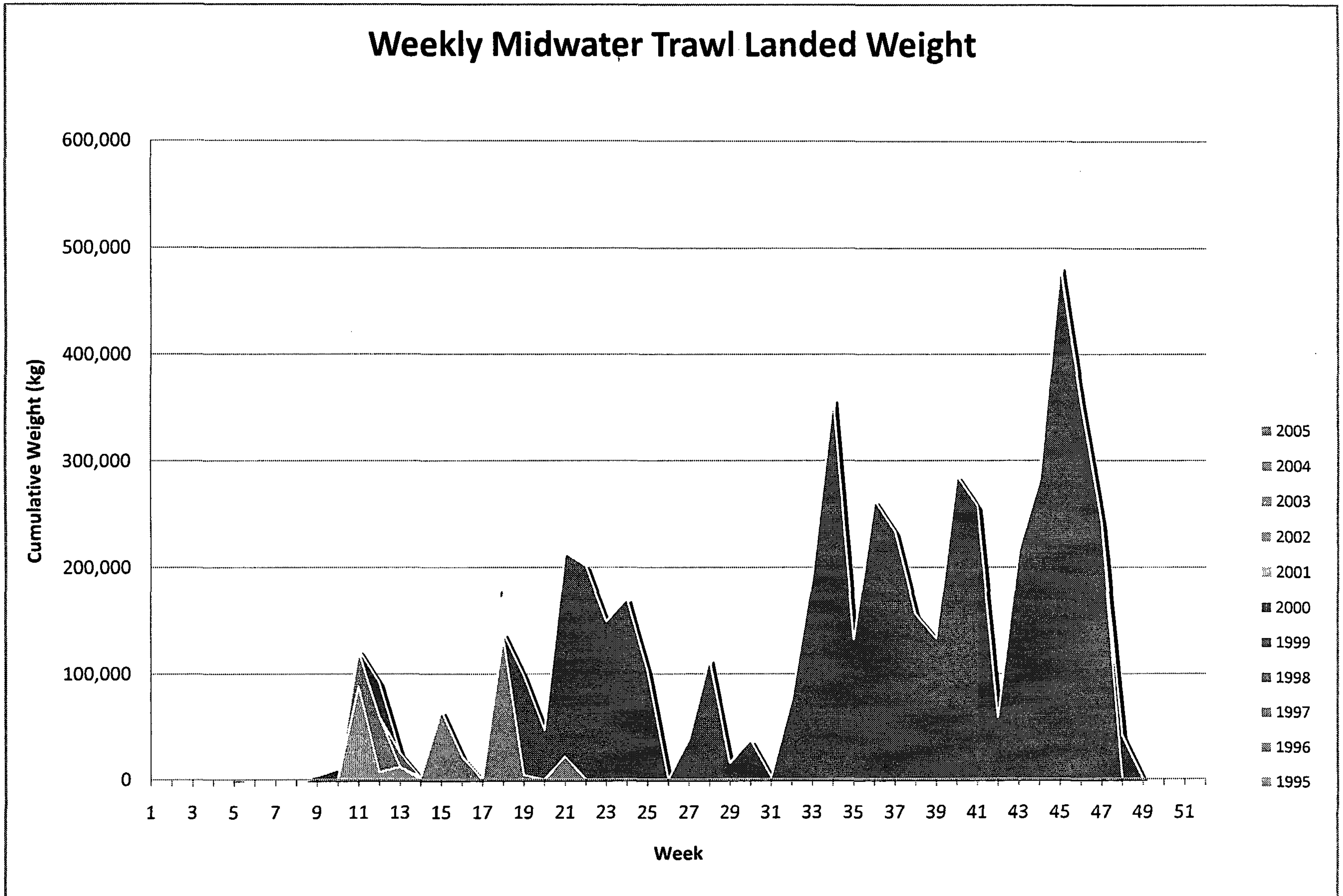

Figure A.5.2 Cumulative Weekly Midwater Trawl Landed Weight. Years 1995-2005.

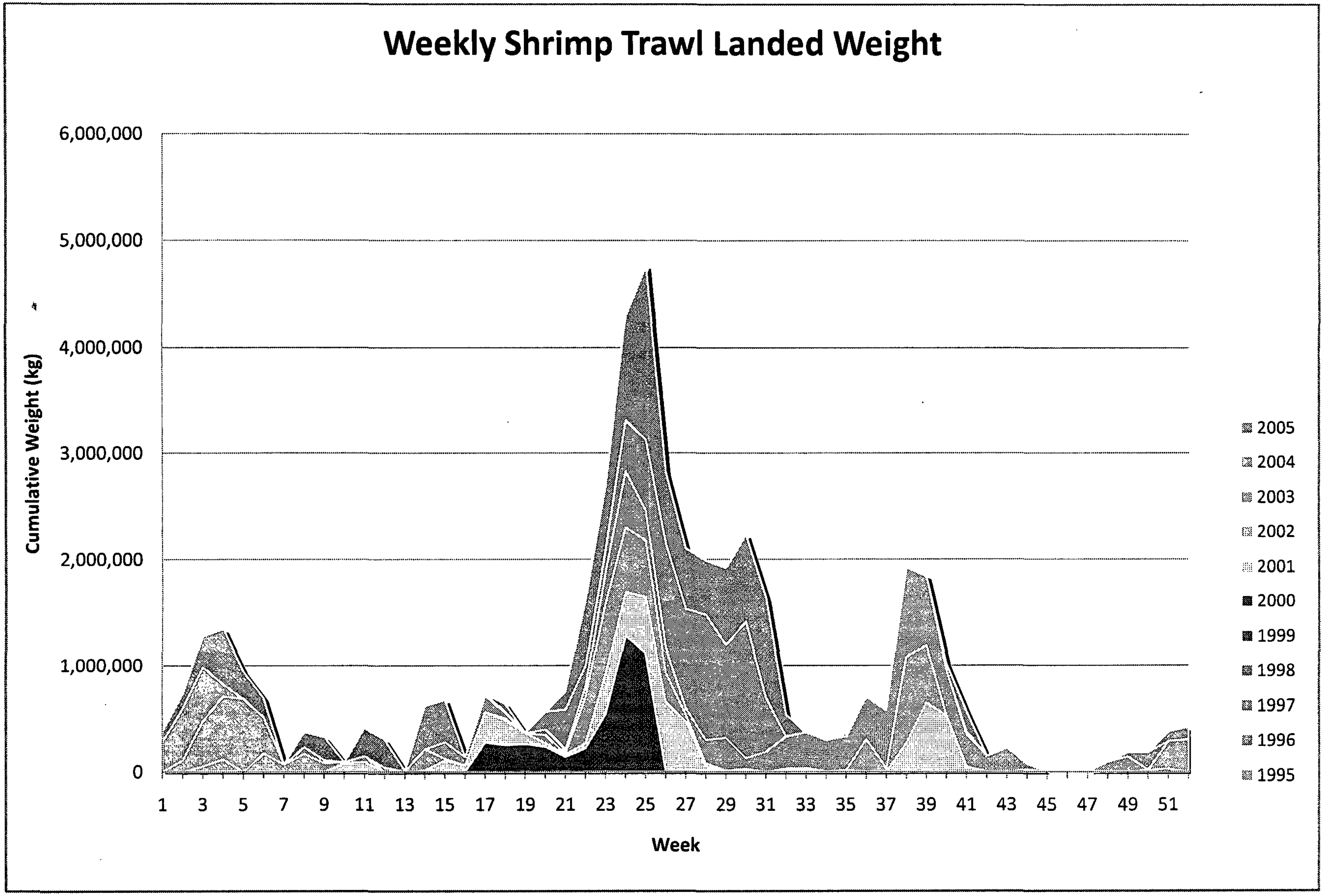

Figure A.5.3 Cumulative Weekly Shrimp Trawl Landed Weight. Years 1995-2005.

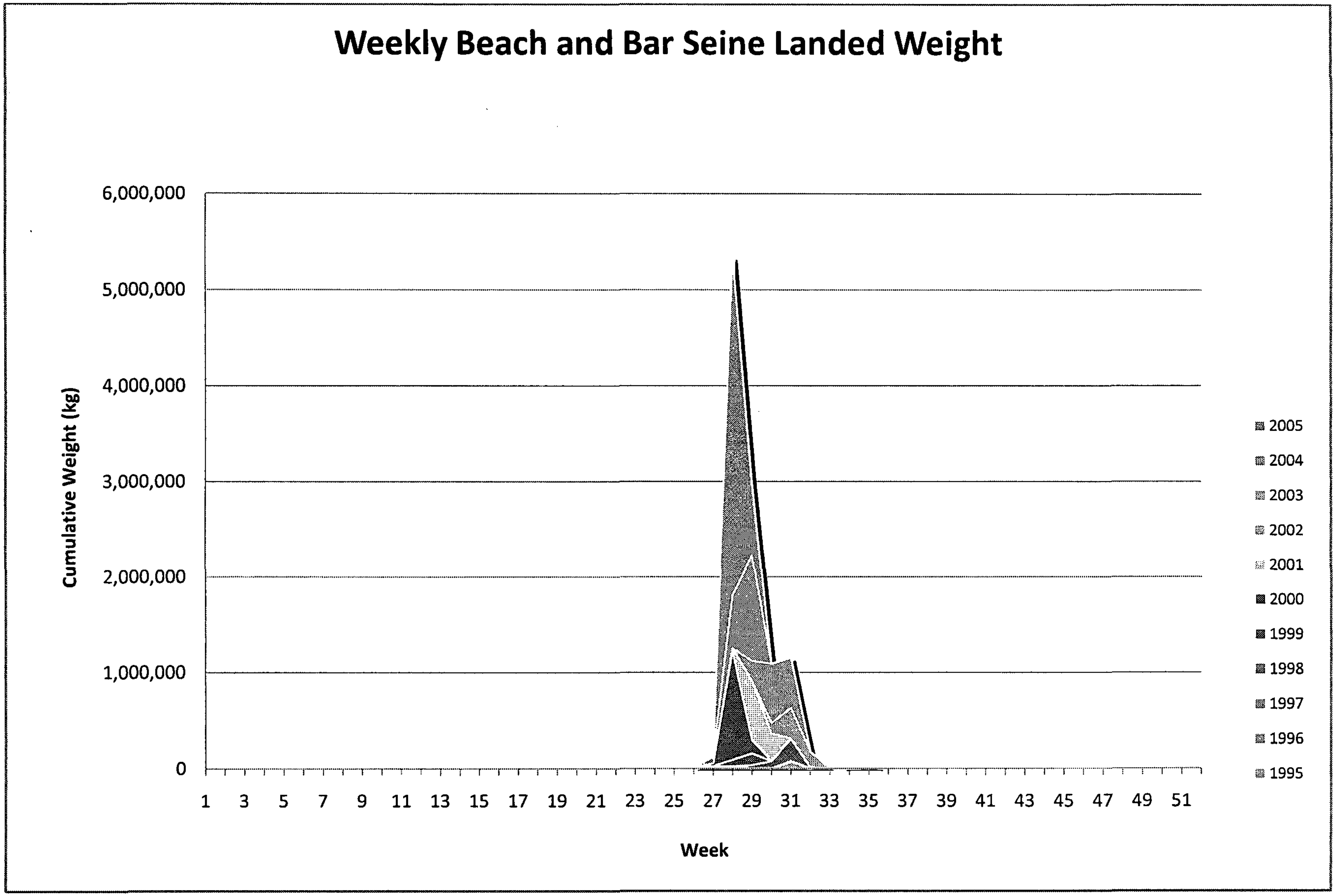

Figure A.5.4 Cumulative Weekly Beach and Bar Seine Landed Weight. Years 1995-2005.

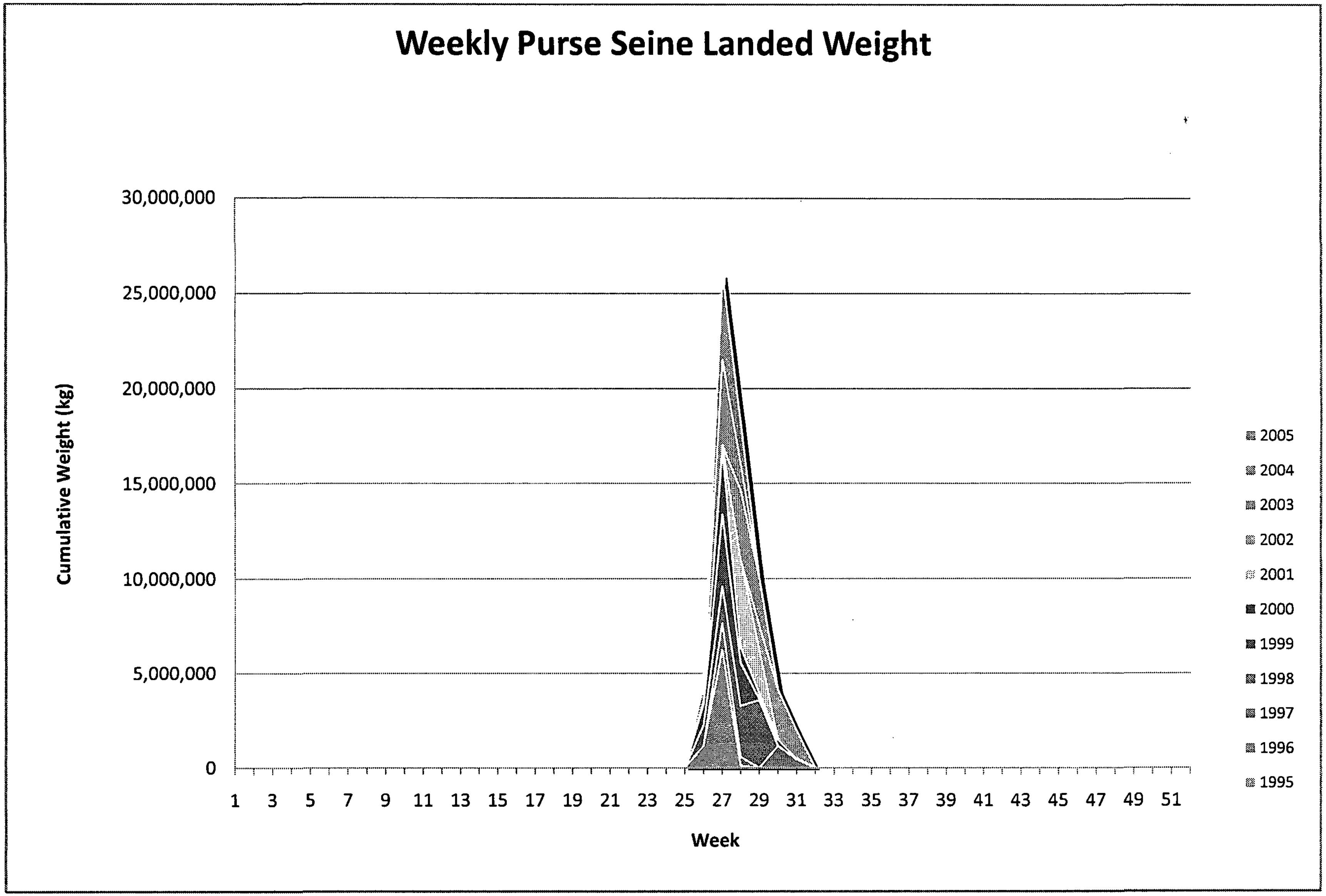

Figure A.5.5 Cumulative Weekly Purse Seine Landed Weight. Years 1995-2005.

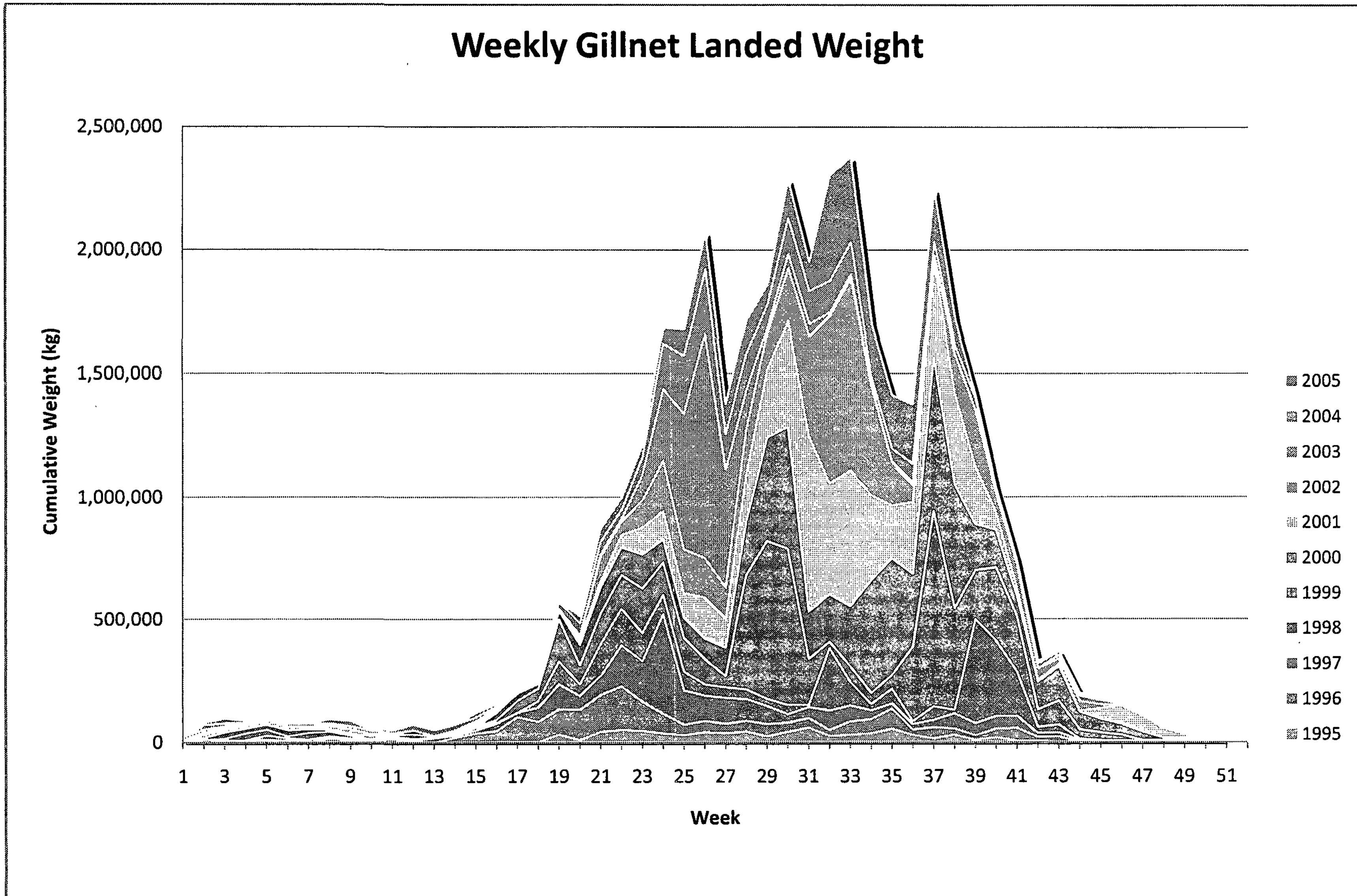

Figure A.5.6 Cumulative Weekly Gillnet Landed Weight. Years 1995-2005.

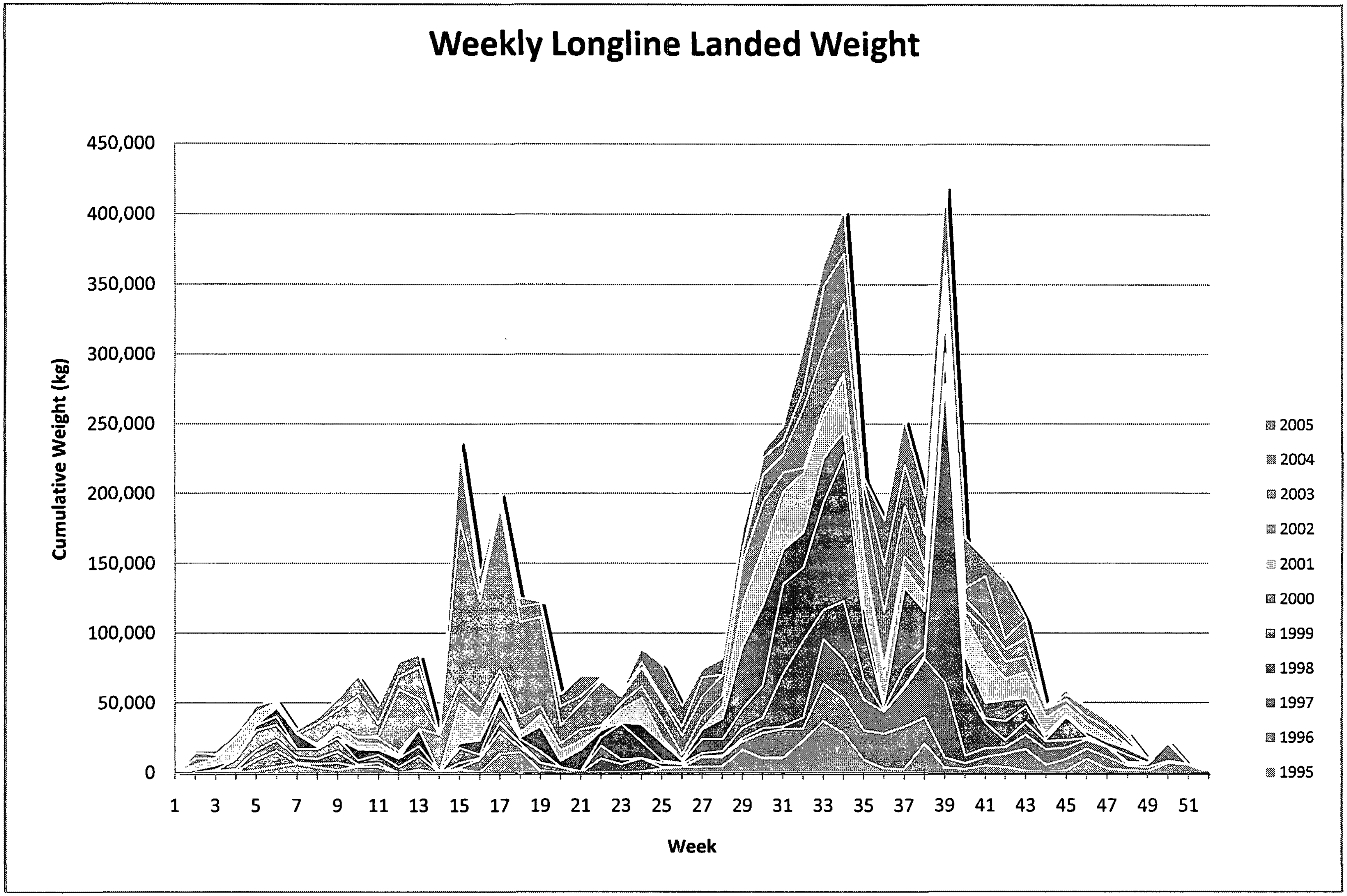

Figure A.5.7 Cumulative Weekly Gillnet Landed Weight. Years 1995-2005.

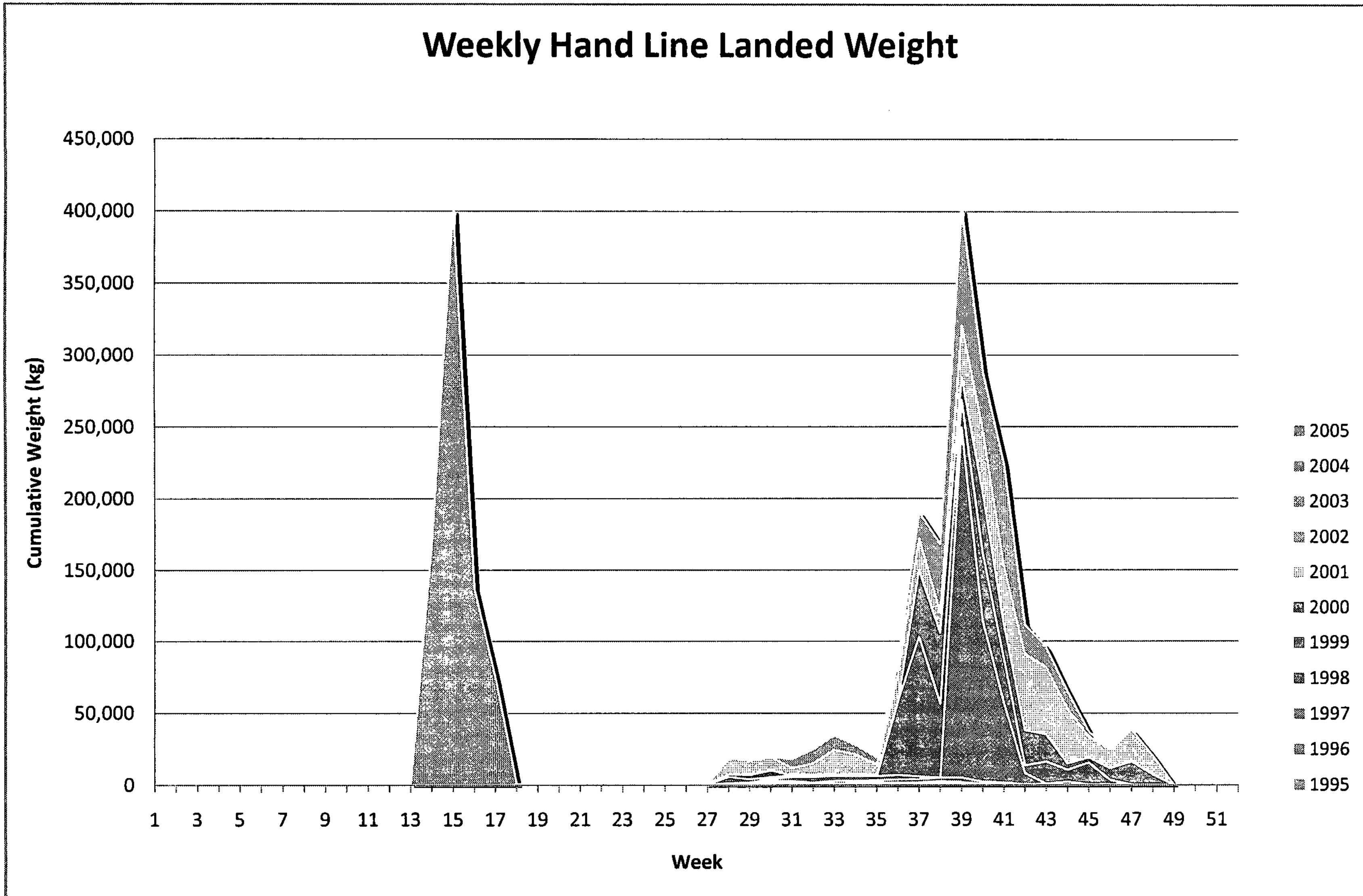

Figure A.5.8 Cumulative Weekly Hand Line Landed Weight. Years 1995-2005.

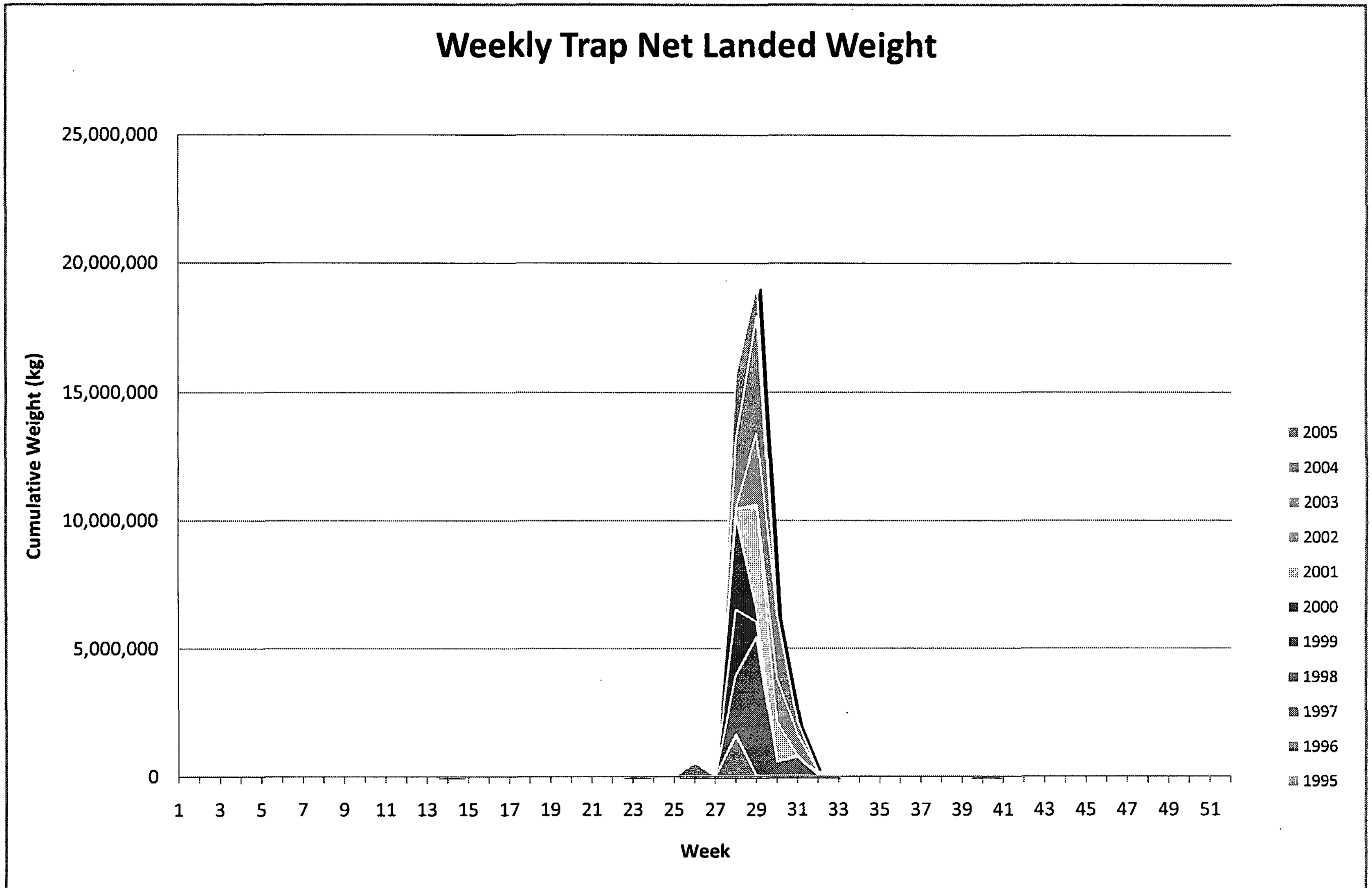

Figure A.5.9 Cumulative Weekly Trap Net Landed Weight. Years 1995-2005.

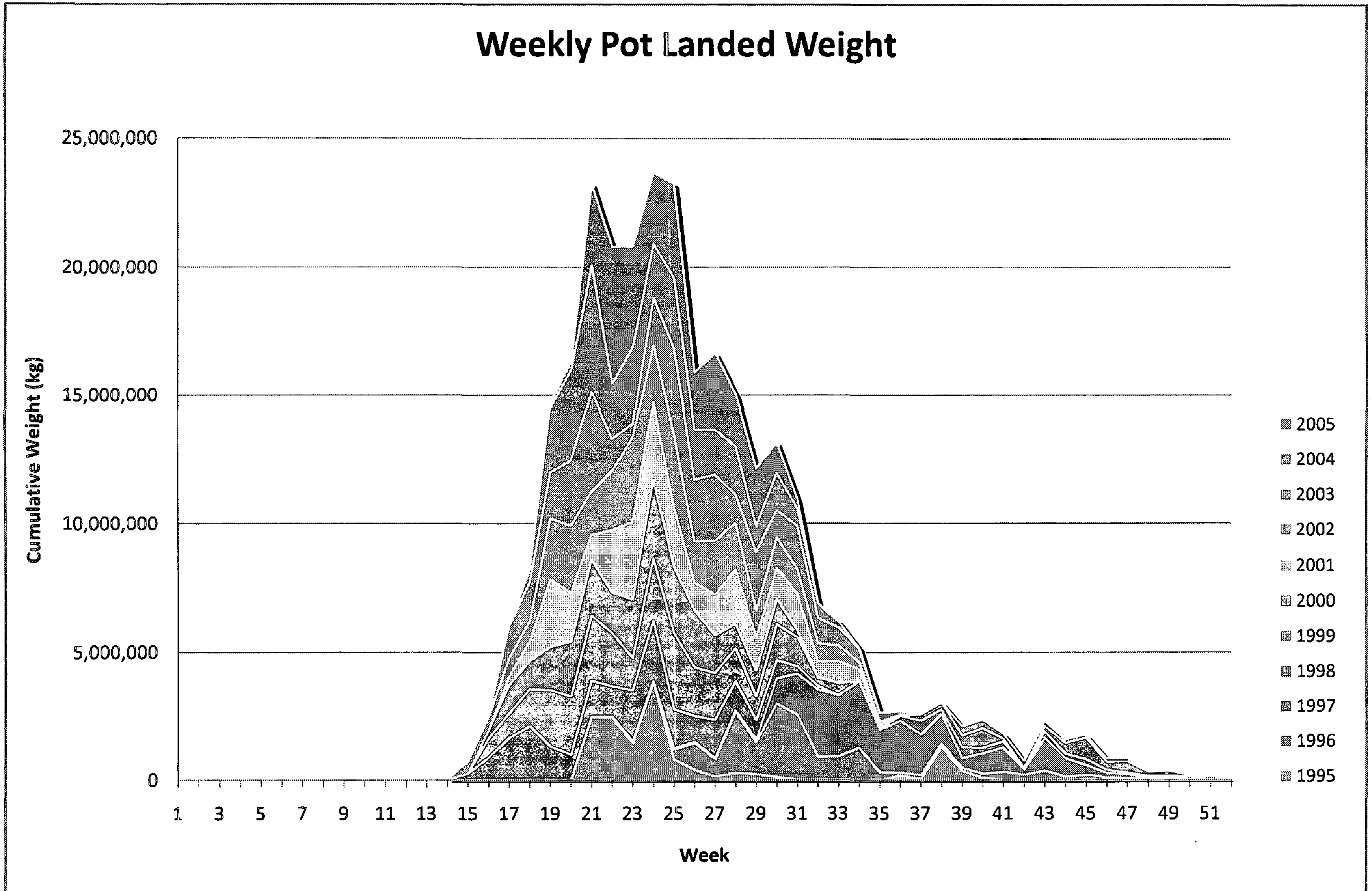

Figure A.5.10 Cumulative Weekly Pot Landed Weight. Years 1995-2005.

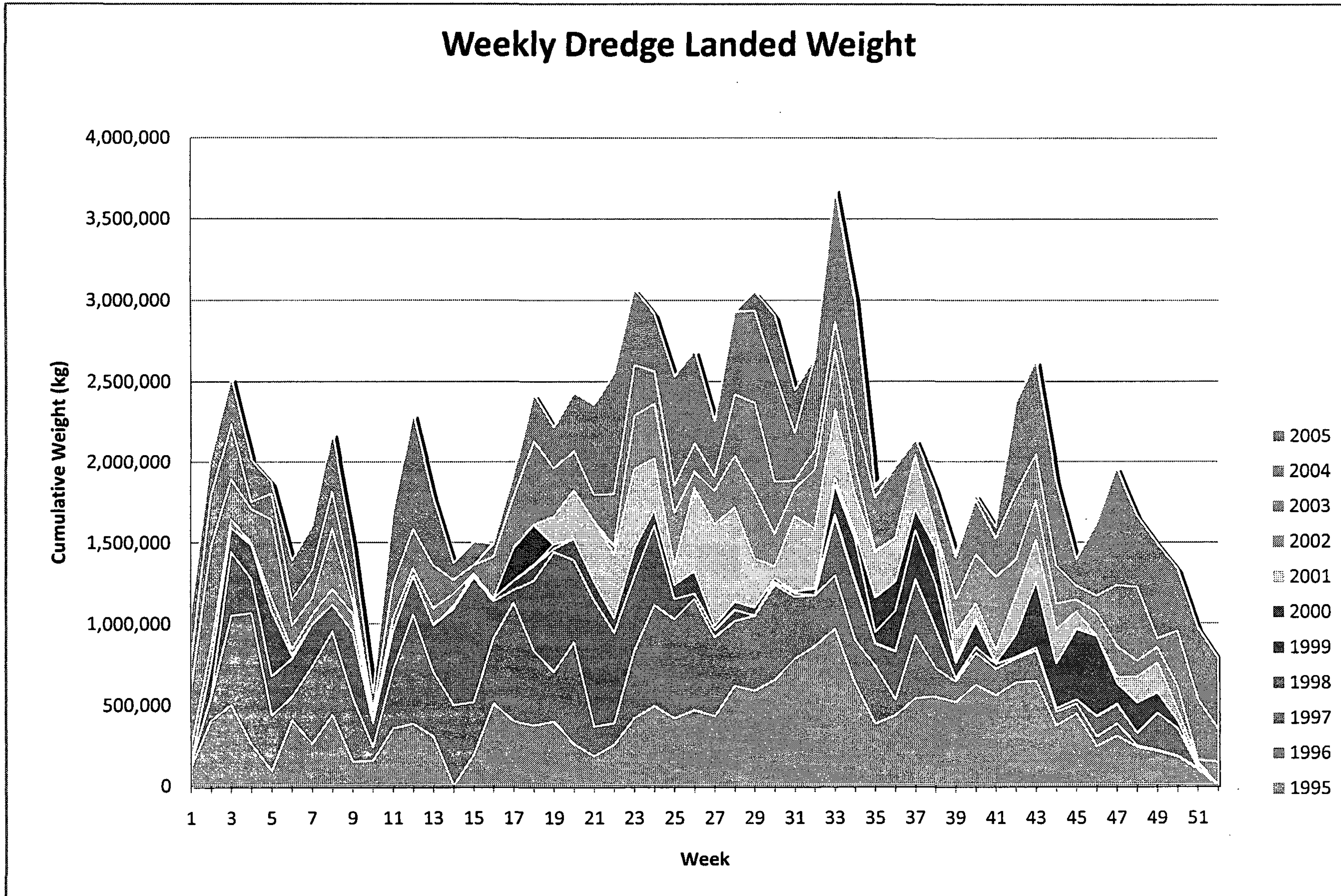

Figure A.5.11 Cumulative Weekly Dredge Landed Weight. Years 1995-2005.

A.6 Gear Type and Species Combinations

Further characterization of the Grand Banks fishing fleet requires the identification of all significant combinations between species and gear types. This is accomplished by examining the average annual catch by gear type for each species and the average annual catch by species for each gear type. An example of the first is the identification of the main gear types that harvest Yellowtail Flounder, and an example of the second is the identification of the main species that are captured by Gillnets. Although there is a large overlap in the information that these analyses provide, the combined data creates important indicators that are instrumental in the selection of significant gear/ species combinations. When a species represents a very small portion of a gear type's landings we can choose not to select that gear and species combination if no other information is available. For example, Trap Net represents 2% of average annual Cod catches but only 1% of its catch is Cod, so we do not include Cod as a significant species for Trap Net. Conversely, if that gear type is the sole method of harvest for the species in question, fact which is quickly revealed by the combined analysis, then it is necessary to select that gear type and species combination. For example, Lobster only represents 1% of Pot landings, but that is the unique gear type that harvests it.

A.6.1 Average Annual 1995-2005 catch by Gear Type for Each Species

In this section we examine the relationship between gear type and species, i.e. which species are prosecuted by each gear type and in what proportion. Table A.6.1 below shows which gear types harvest each species. For Species that are harvested by more than one gear type, Figure A.6.1 toFigure A.6.8 show the percentage of total catches and the corresponding weight captured by each gear type.

Table A.6.1 Main Gear Types Used for Prosecuting Each Species

Species	Gear Type
Cod	Gillnet, Bottom Otter Trawl, Hand Line, Longline, Trap Net
Redfish	Bottom Otter Trawl, Midwater Trawl
Atlantic Halibut	Longline, Gillnet, Bottom Otter Trawl.
American Plaice	Bottom Otter Trawl, Gillnet, Midwater Trawl
Yellowtail Flounder	Bottom Otter Trawl, Longline
Greenland Halibut	Gillnet, Bottom Otter Trawl, Longline
Monkfish	Gillnet, Bottom Otter Trawl
Swordfish	Longline
Capelin	Beach and Bar Seine, Purse Seine, Trap Net
Clams	Dredge
Cockles and Scallops	Dredge
Lobster	Pot
Northern Shrimp	Shrimp Trawl
Snow Crab	Pot
Lumpfish	Gillnet

Beach and Bar Seine, Purse Seine and Trap Net are all used to capture Capelin, which explains why they operate at similar times as we observed in the time analysis illustration for this species presented in section 3.3 above. The above table, Table A.6.1 clearly illustrates that some species are prosecuted by one gear type only, as is the case with Shrimp, Clams, Cockles, Scallops, Lobster, and Snow Crab. This information is derived from average annual catch data for the years 1995-2005. In the next step we refine the analysis of the catch by examining annual values.

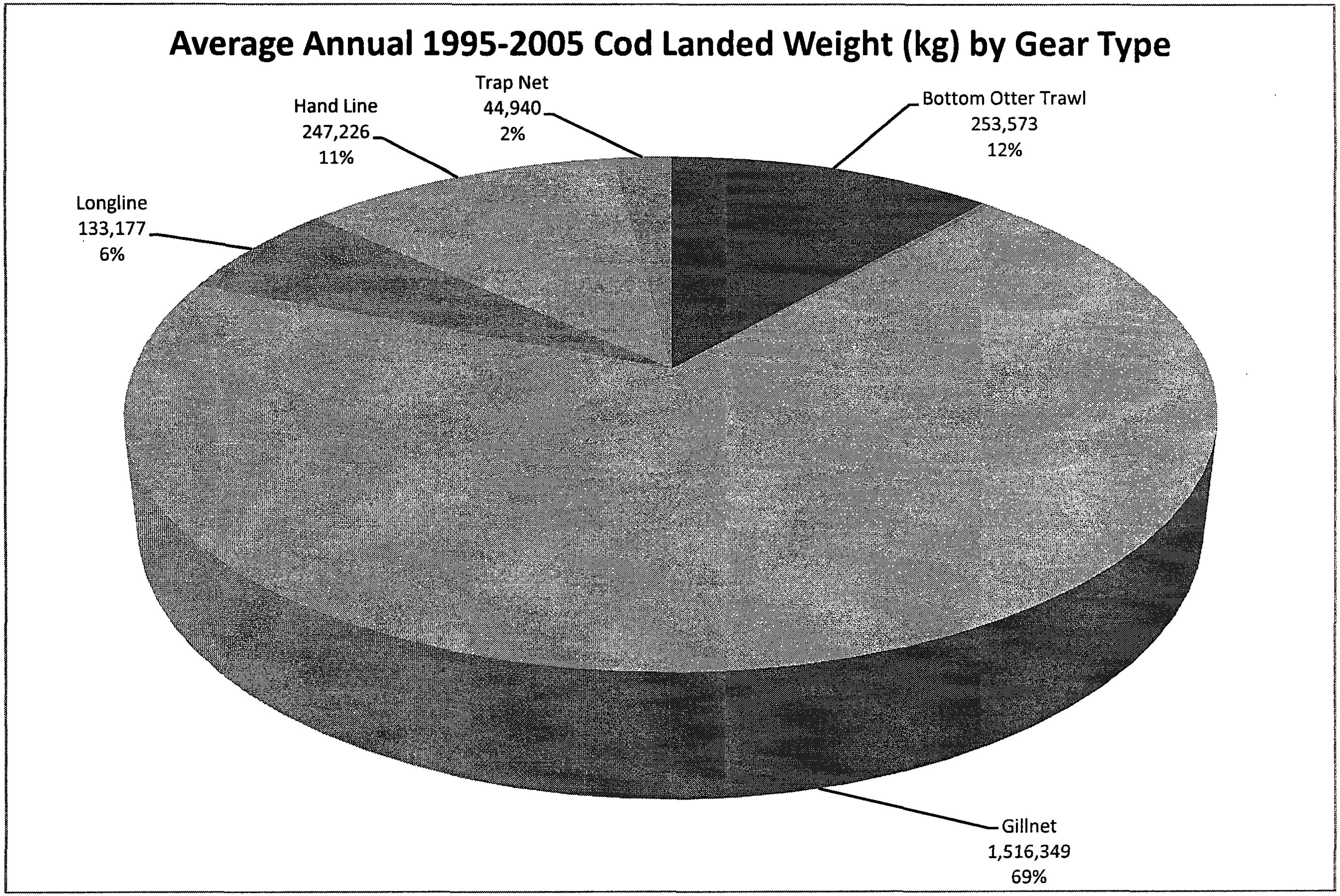

Figure A.6.1 Average Annual Cod Landed Weight by Gear Type. Years 1995-2005.

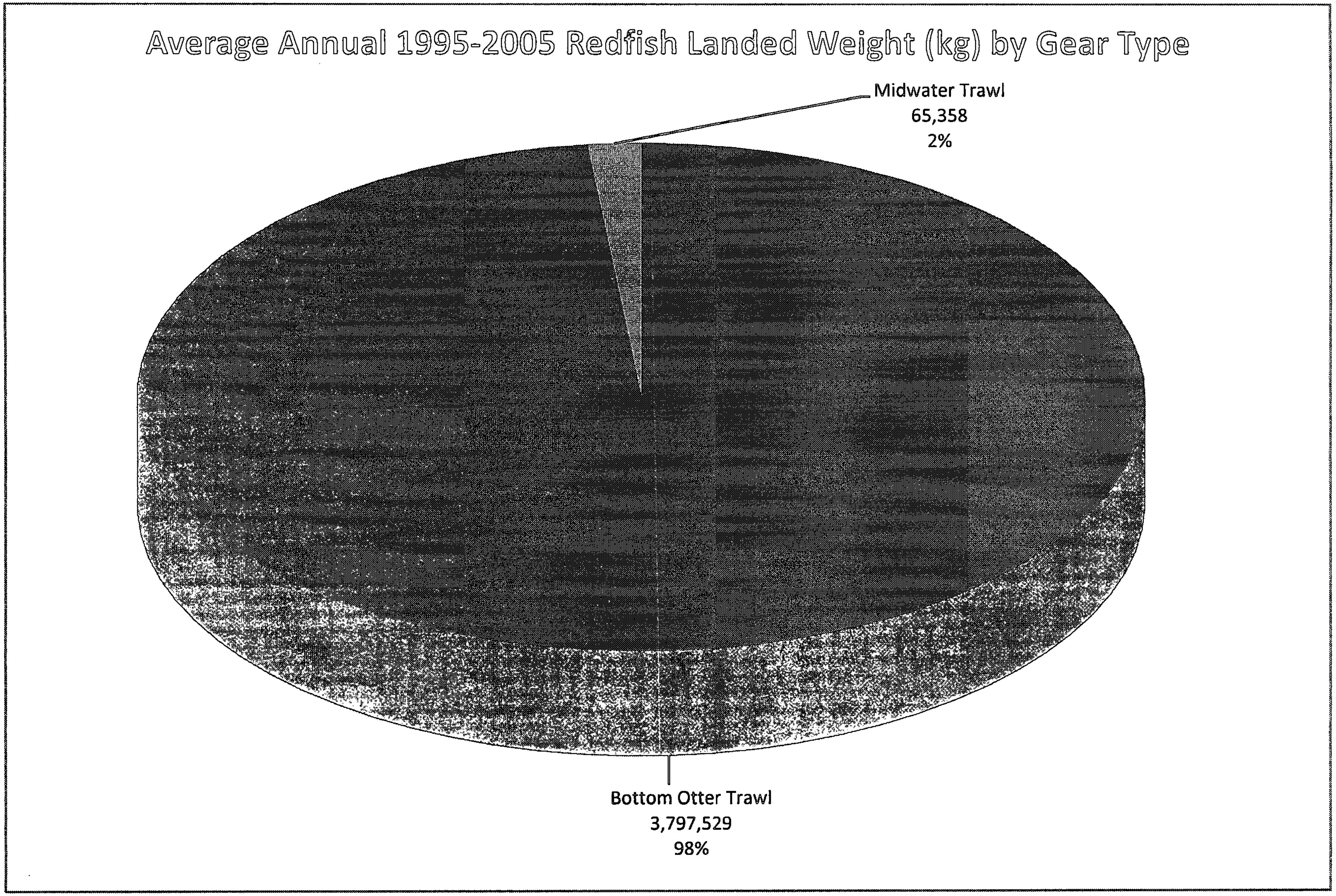

Figure A.6.2 Average Annual Redfish Landed Weight by Gear Type. Years 1995-2005.

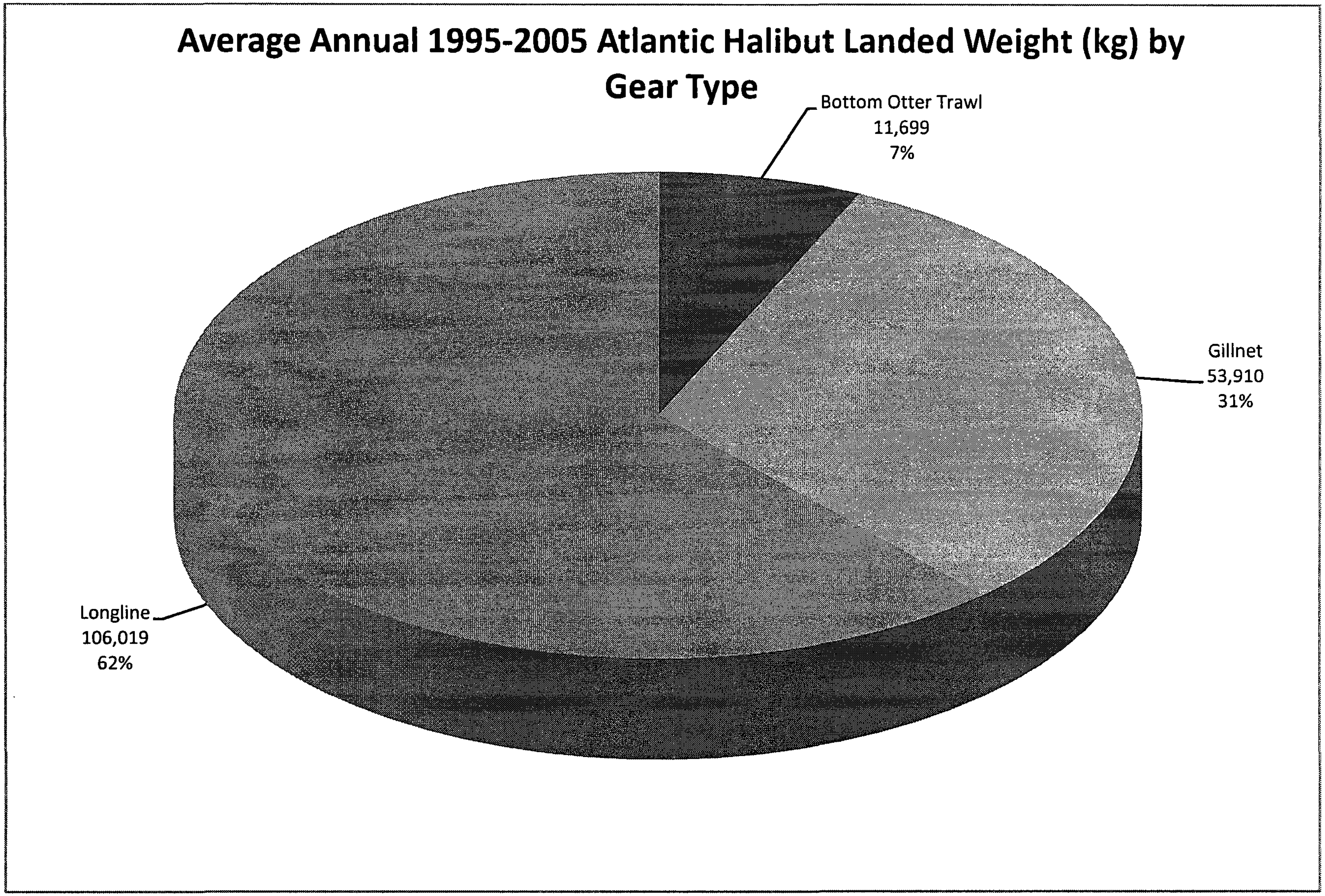

Figure A.6.3Average Annual Atlantic Halibut Landed Weight by Gear Type. Years 1995-2005.

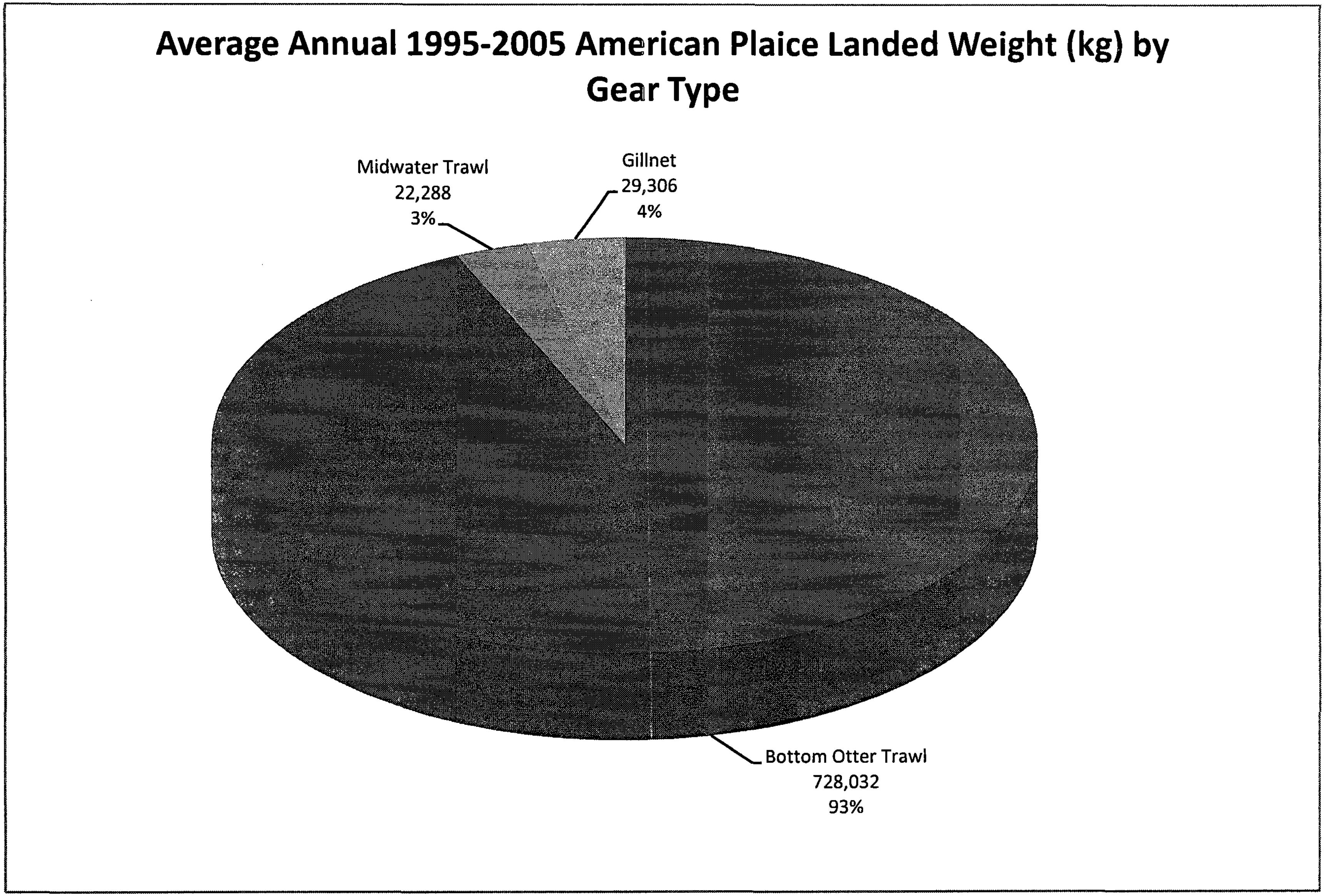

Figure A.6.4 Average Annual American Plaice Landed Weight by Gear Type. Years 1995-2005.

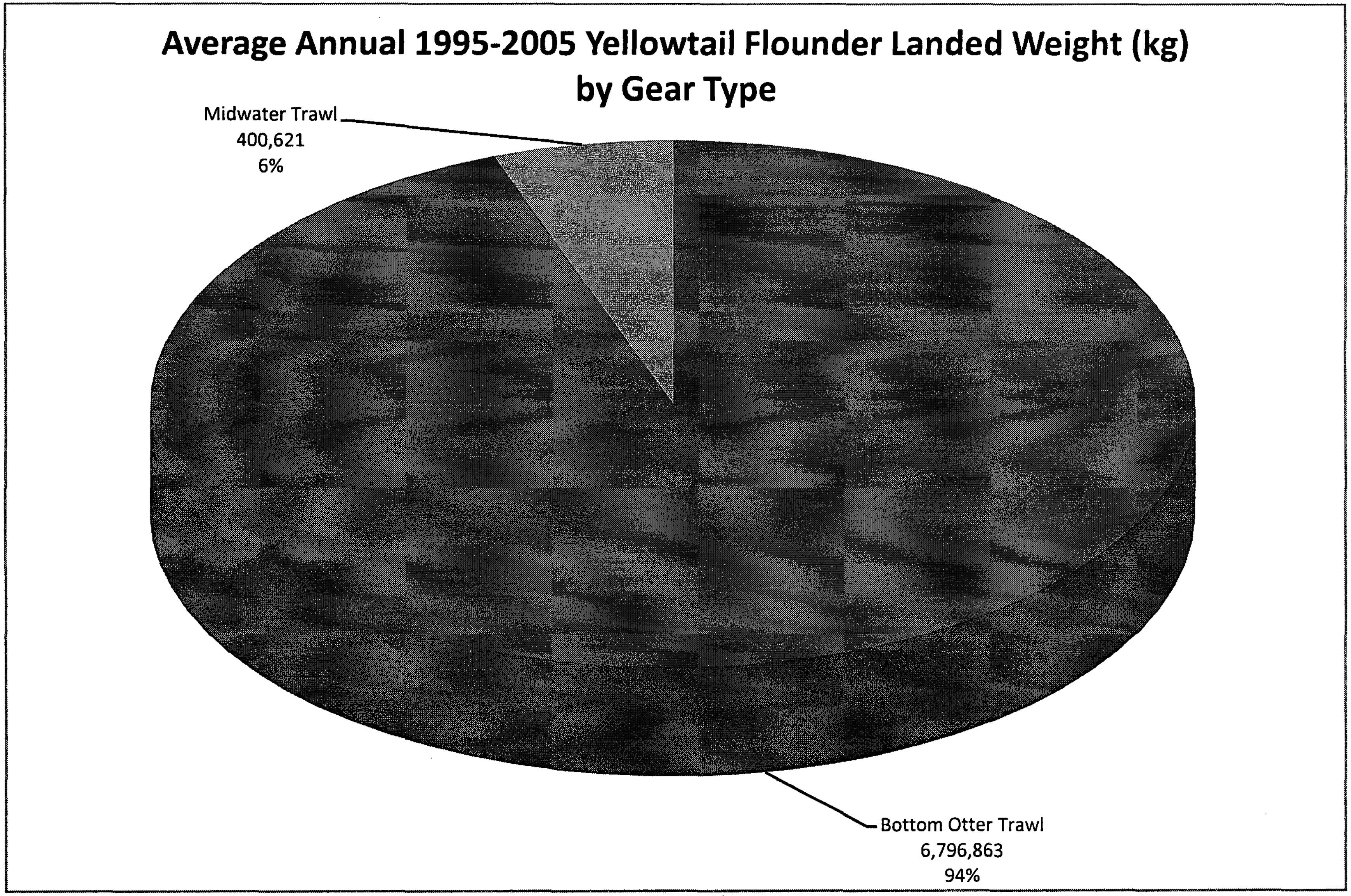

Figure A.6.5 Average Annual Yellowtail Flounder Landed Weight by Gear Type. Years 1995-2005.

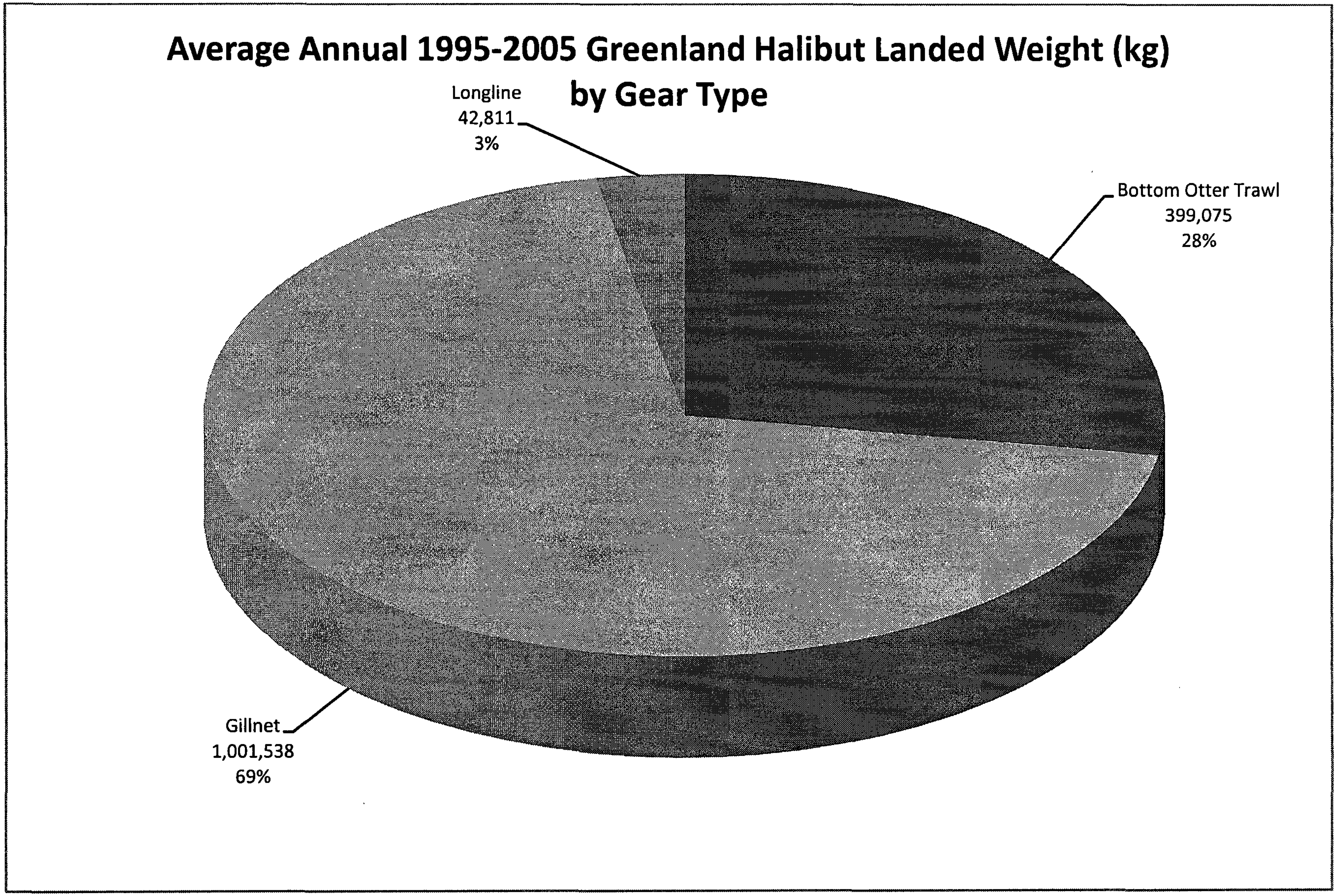

Figure A.6.6 Average Annual Greenland Halibut Landed Weight by Gear Type. Years 1995-2005.

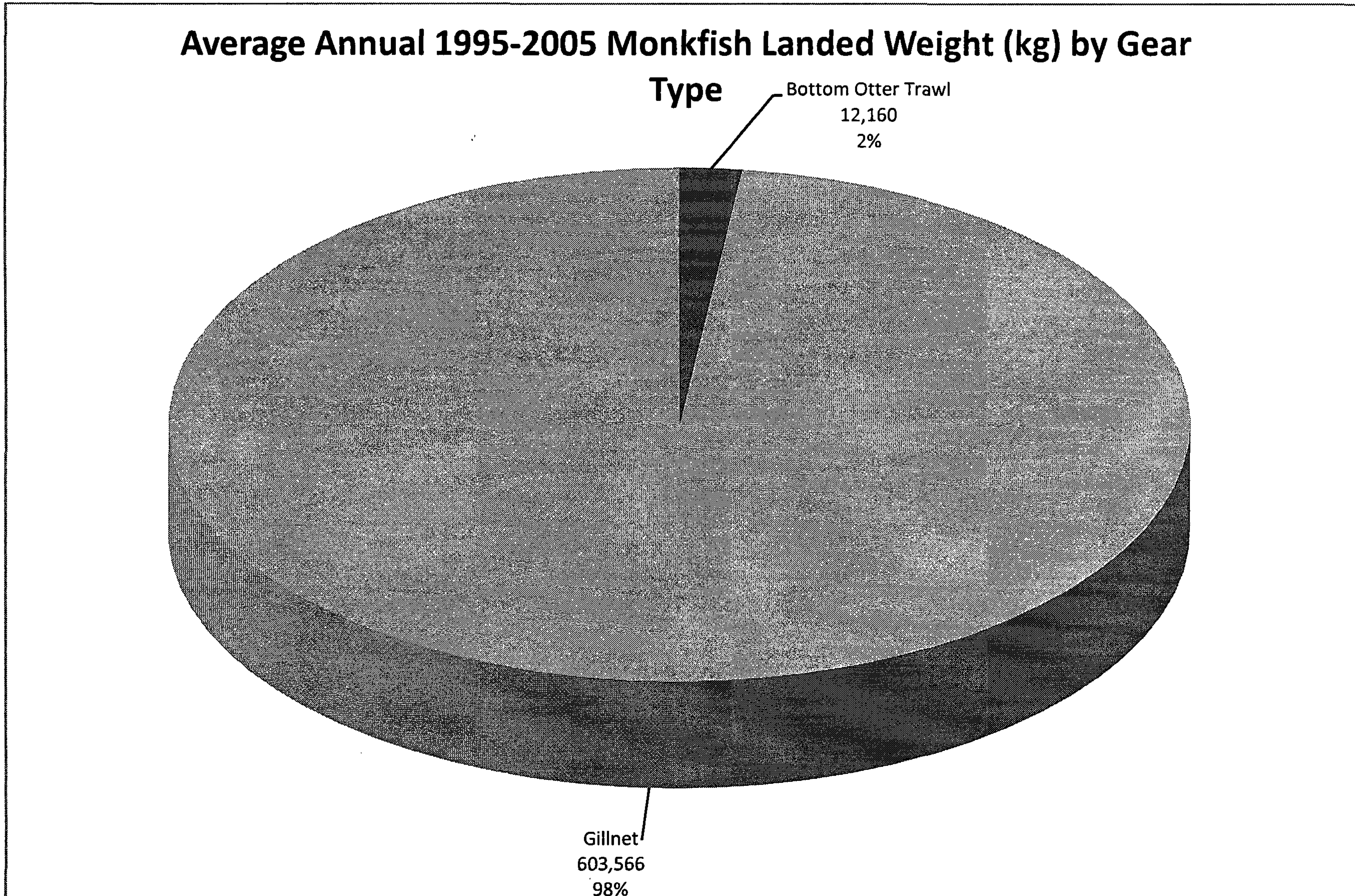

Figure A.6.7 Average Annual Monkfish Landed Weight by Gear Type. Years 1995-2005.

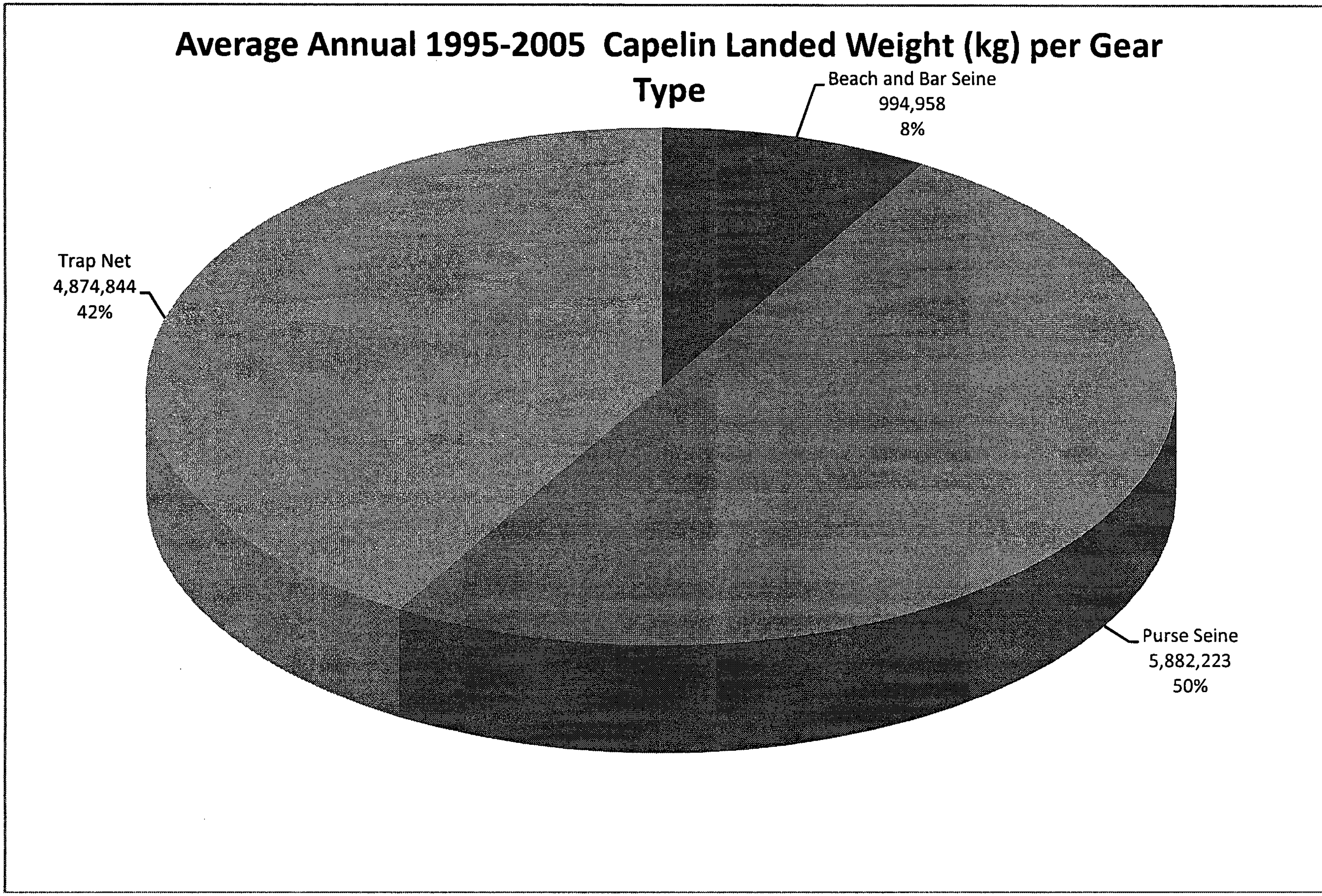

Figure A.6.8 Average Annual Capelin Landed Weight by Gear Type. Years 1995-2005.

A.6.2 Annual Catch by Gear Type for each Species

We continue our analysis by examining the annual catch by gear type for each species. For those species that are only captured by one gear type, we can observe the evolution of the annual catch from 1995 to 2005, and, for those that are harvested by several gear types, we can also examine the relative proportion of catches by gear type for each species. Year-to-year variations can be very large, as illustrated inFigure A.6.9where Cod catches increase from under 300 tonnes in 1995 to over 5,000 tonnes in 1999. However, the relative proportion of landed weight of each gear type remains approximately the same every year, except for Midwater trawlers that show exceptionally high catches in 1999. Also, Bottom Otter Trawl is more active from 2000 through to 2005, and Shrimp Trawl only starts showing significant catches in the year 2000. The next step in the characterization of the Grand Banks fisheries consist of the analysis of the landed weight by species for each gear type.

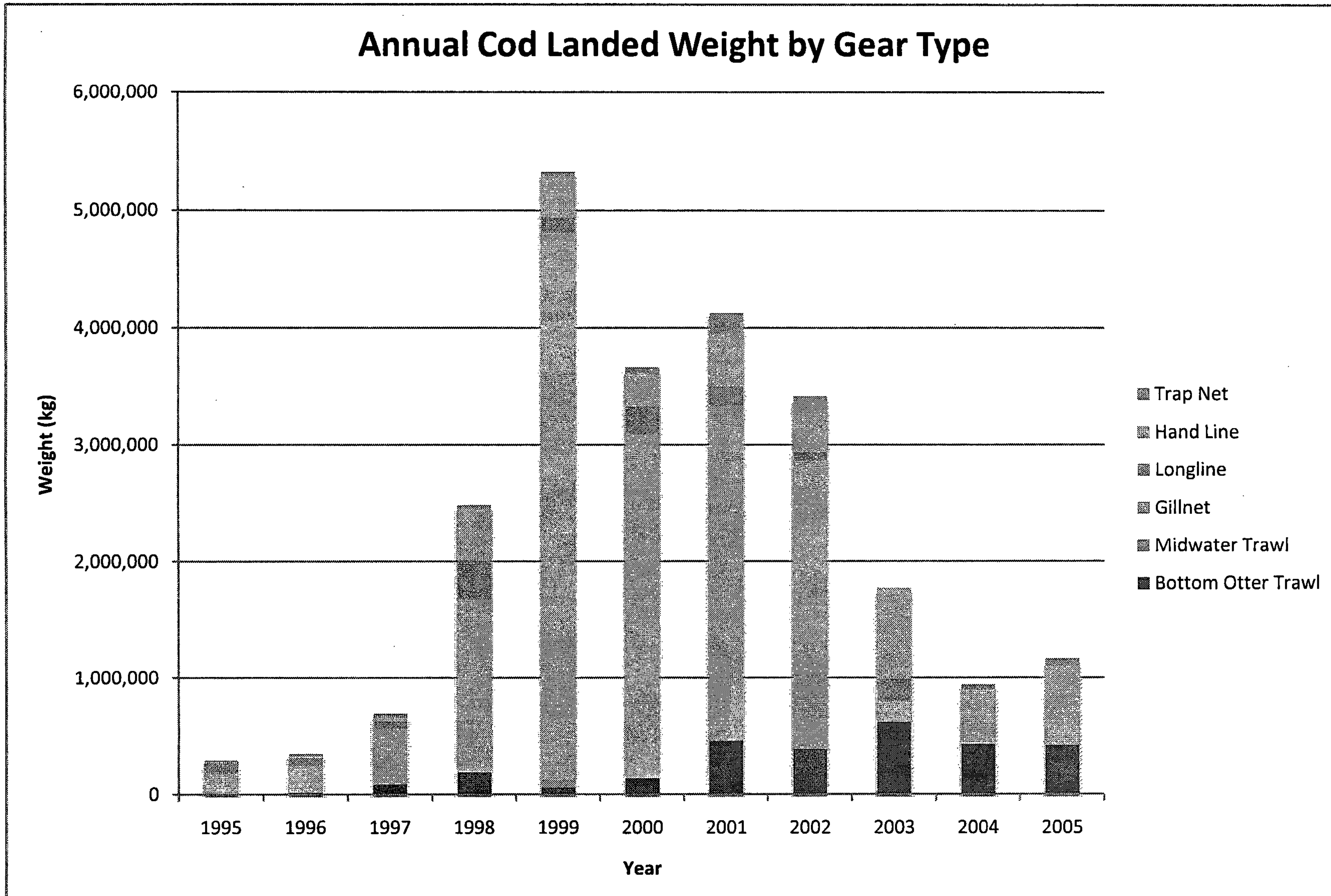

Figure A.6.9 Annual Cod Landed Weight by Gear Type. Years 1995-2005.

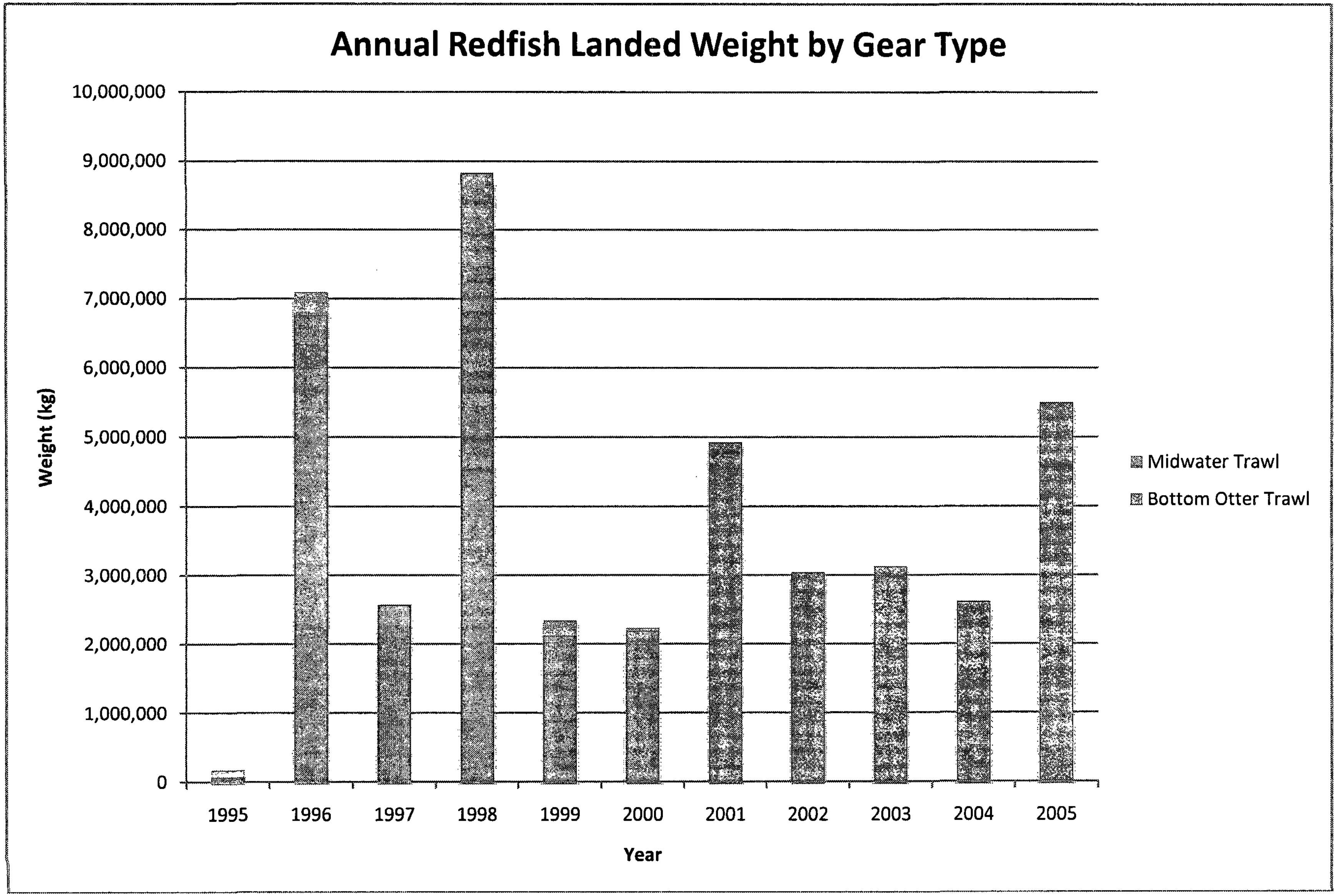

Figure A.6.10 Annual Redfish Landed Weight by Gear Type. Years 1995-2005.

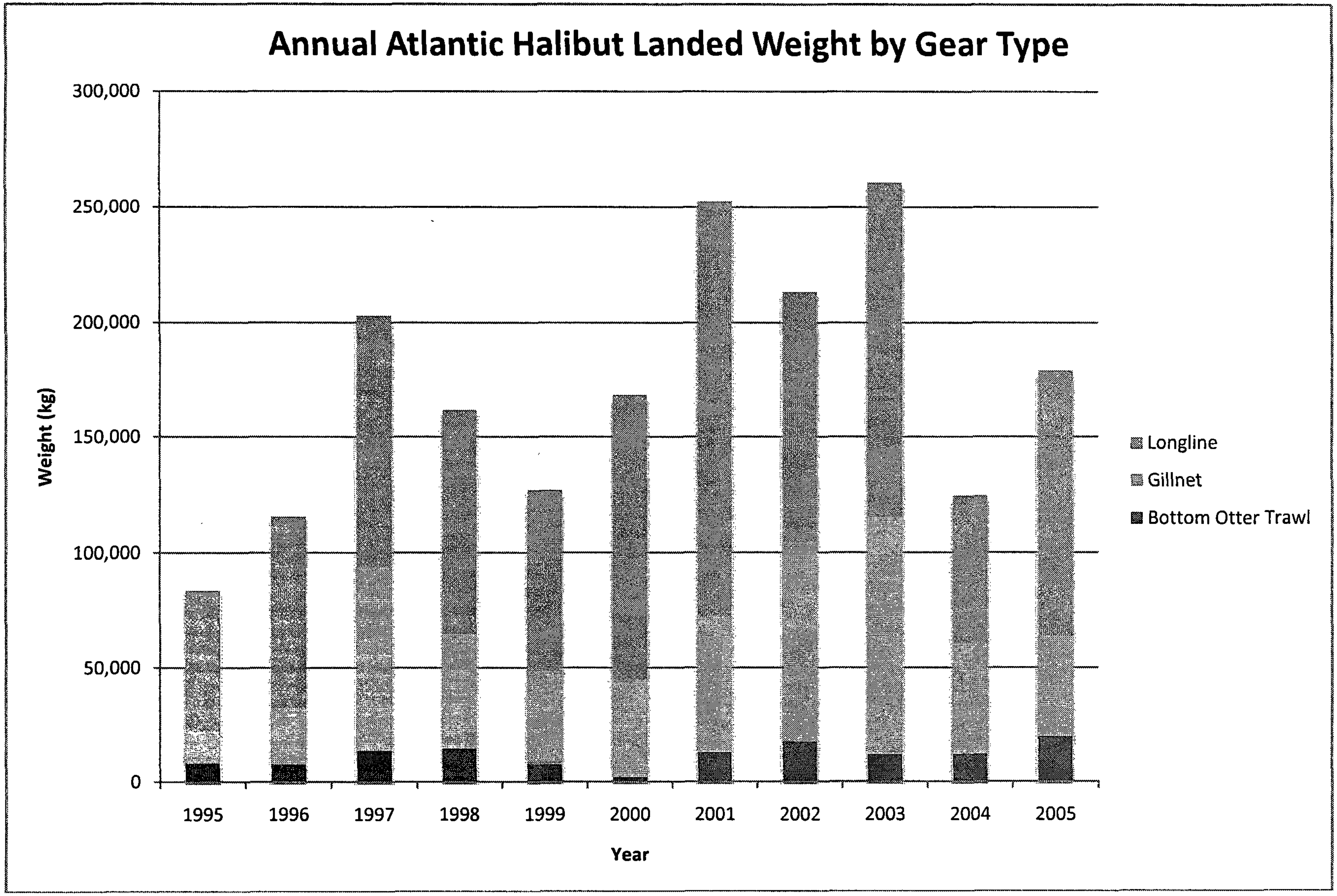

Figure A.6.11 Annual Atlantic Halibut Landed Weight by Gear Type. Years 1995-2005.

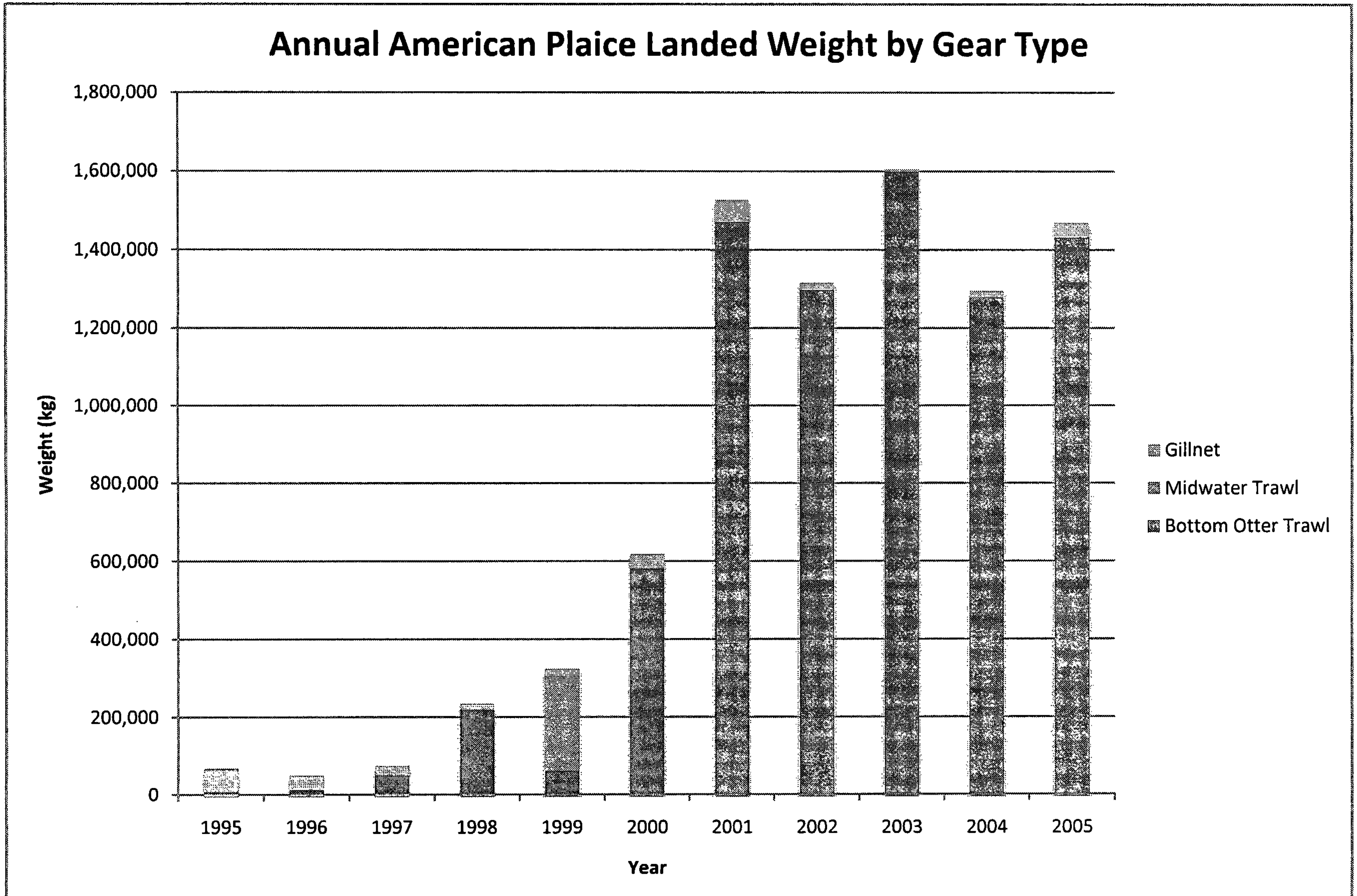

Figure A.6.12 Annual American Plaice Landed Weight by Gear Type. Years 1995-2005.

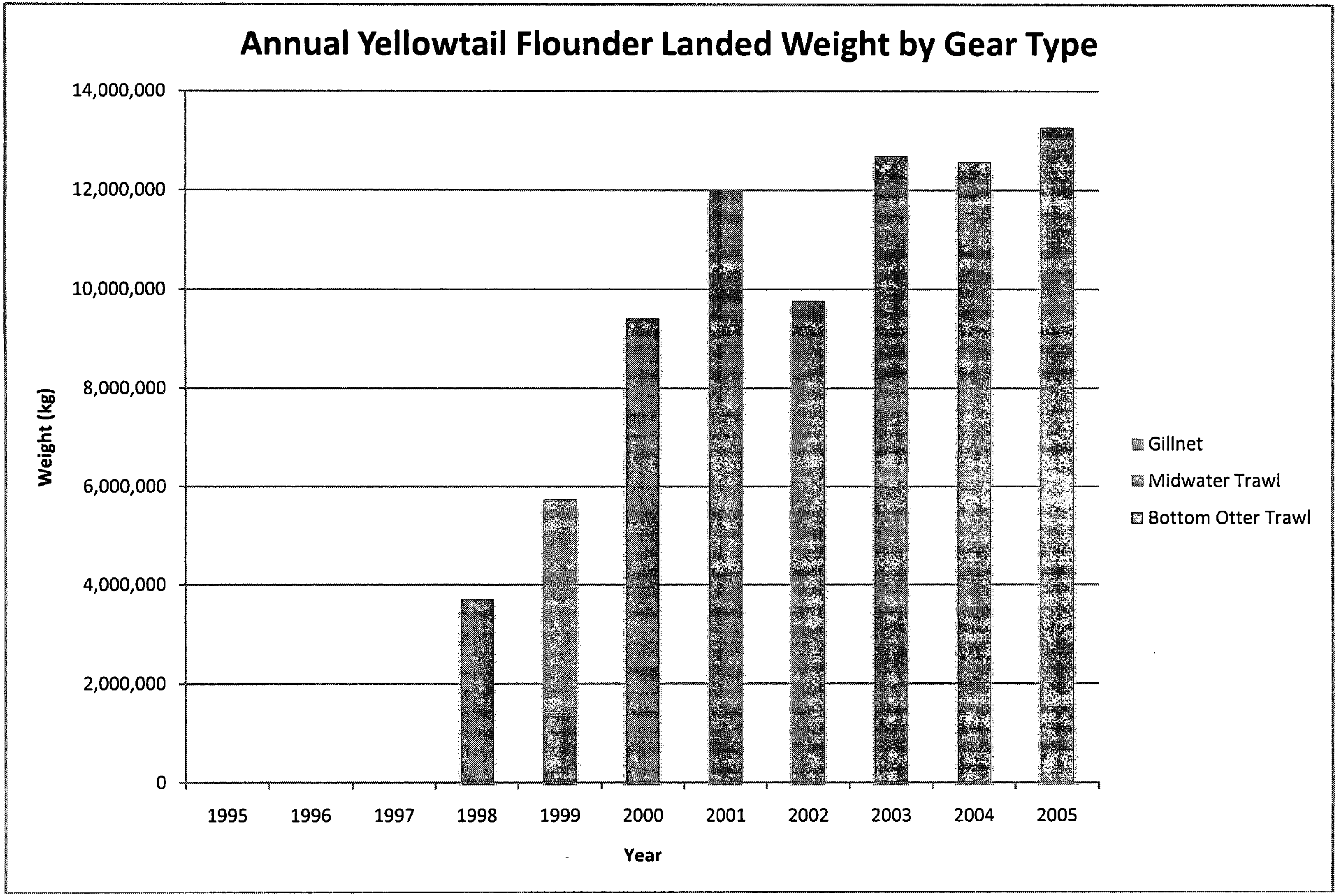

Figure A.6.13 Annual Yellowtail Flounder Landed Weight by Gear Type. Years 1995-2005.

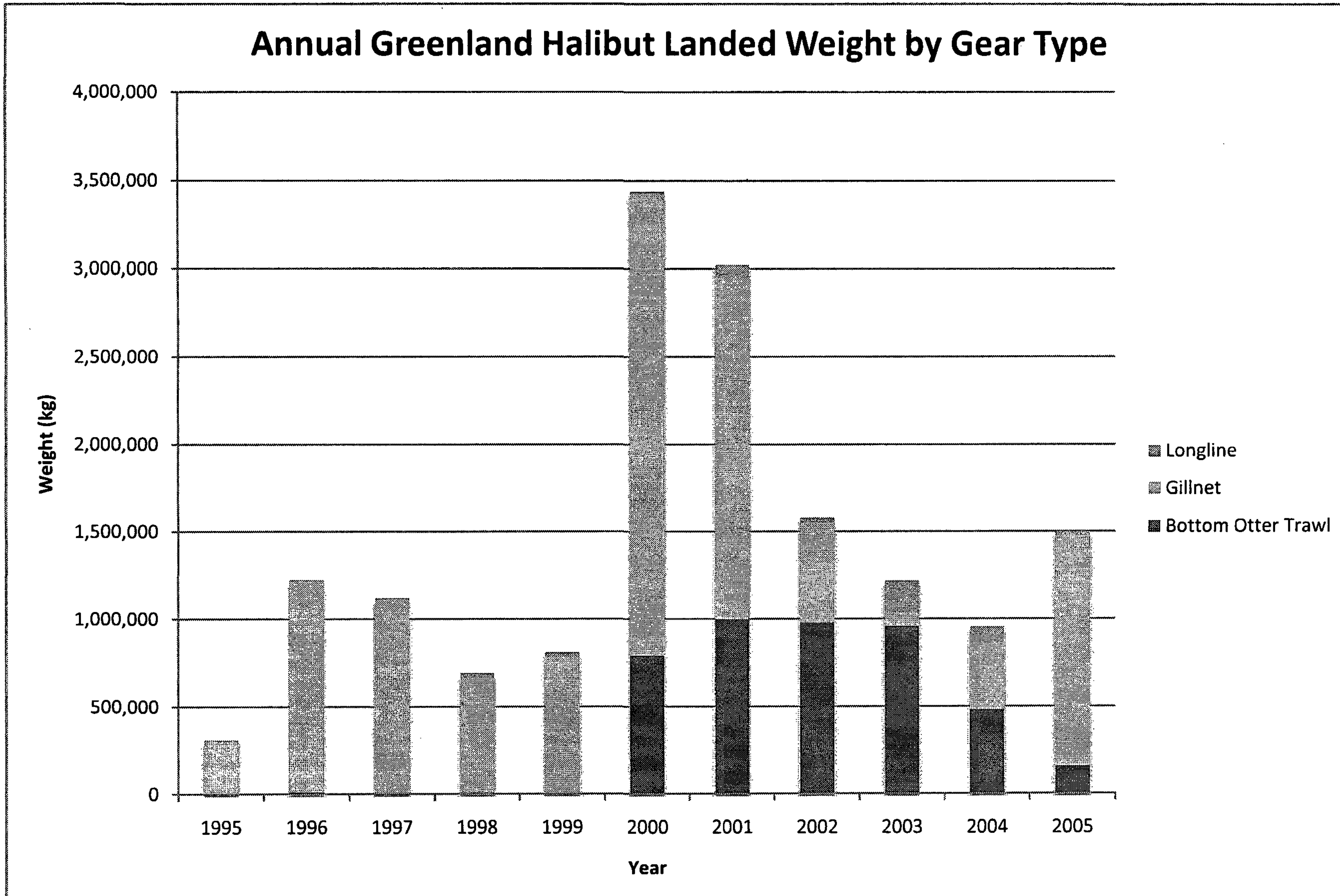

Figure A.6.14 Annual Greenland Halibut Landed Weight by Gear Type. Years 1995-2005.

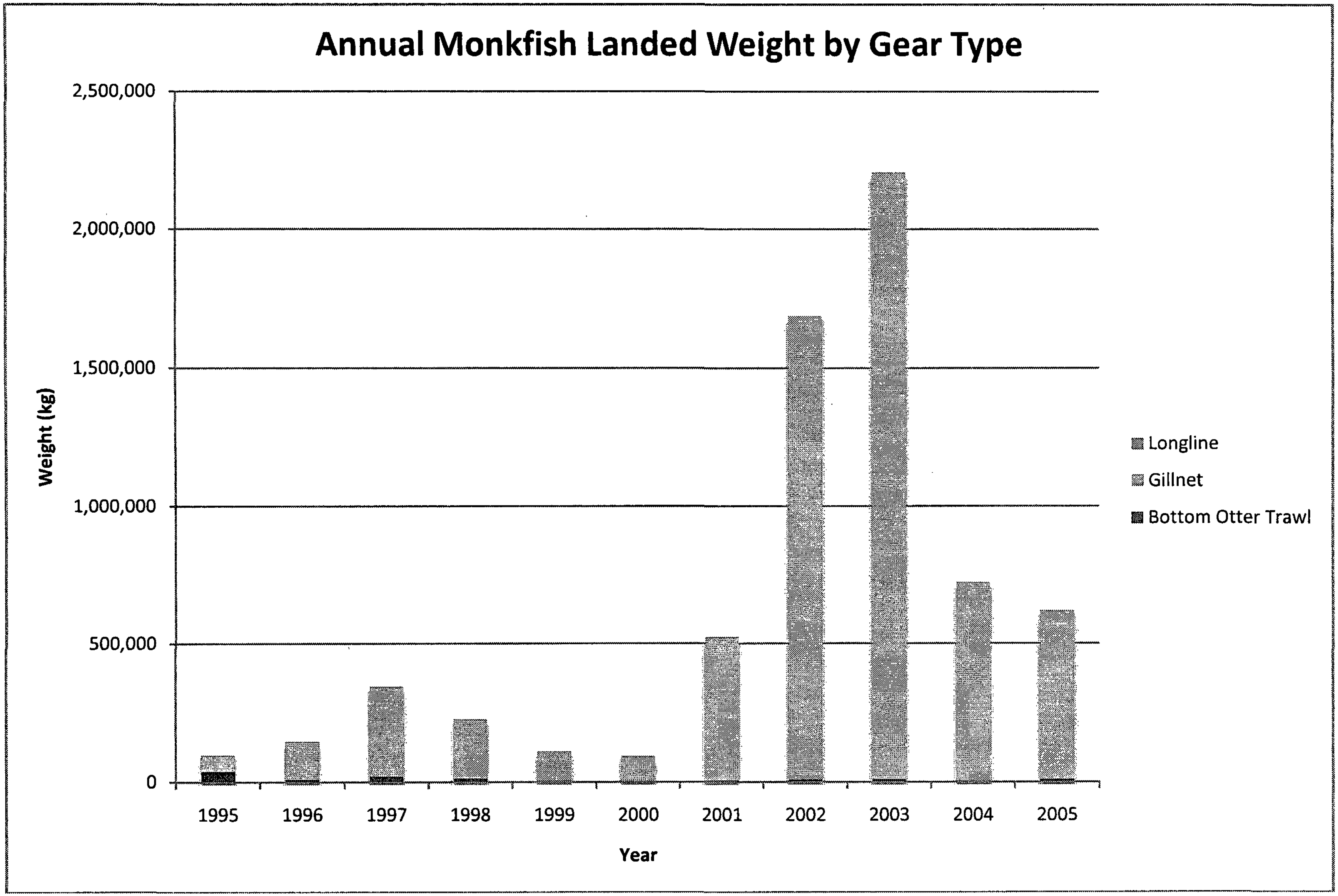

Figure A.6.15 Annual Monkfish Landed Weight by Gear Type. Years 1995-2005.

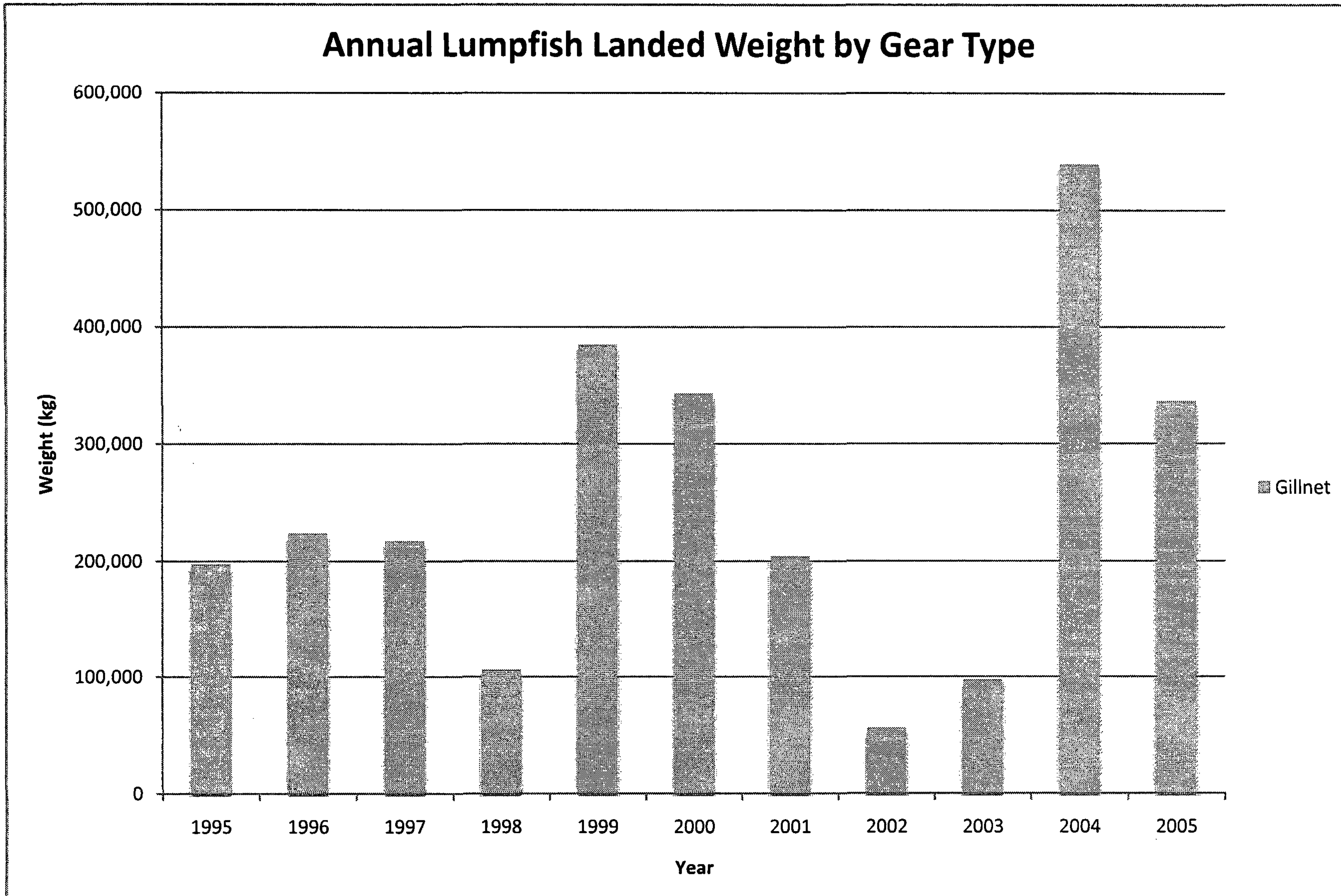

Figure A.6.16 Annual Lumpfish Landed Weight by Gear Type. Years 1995-2005.

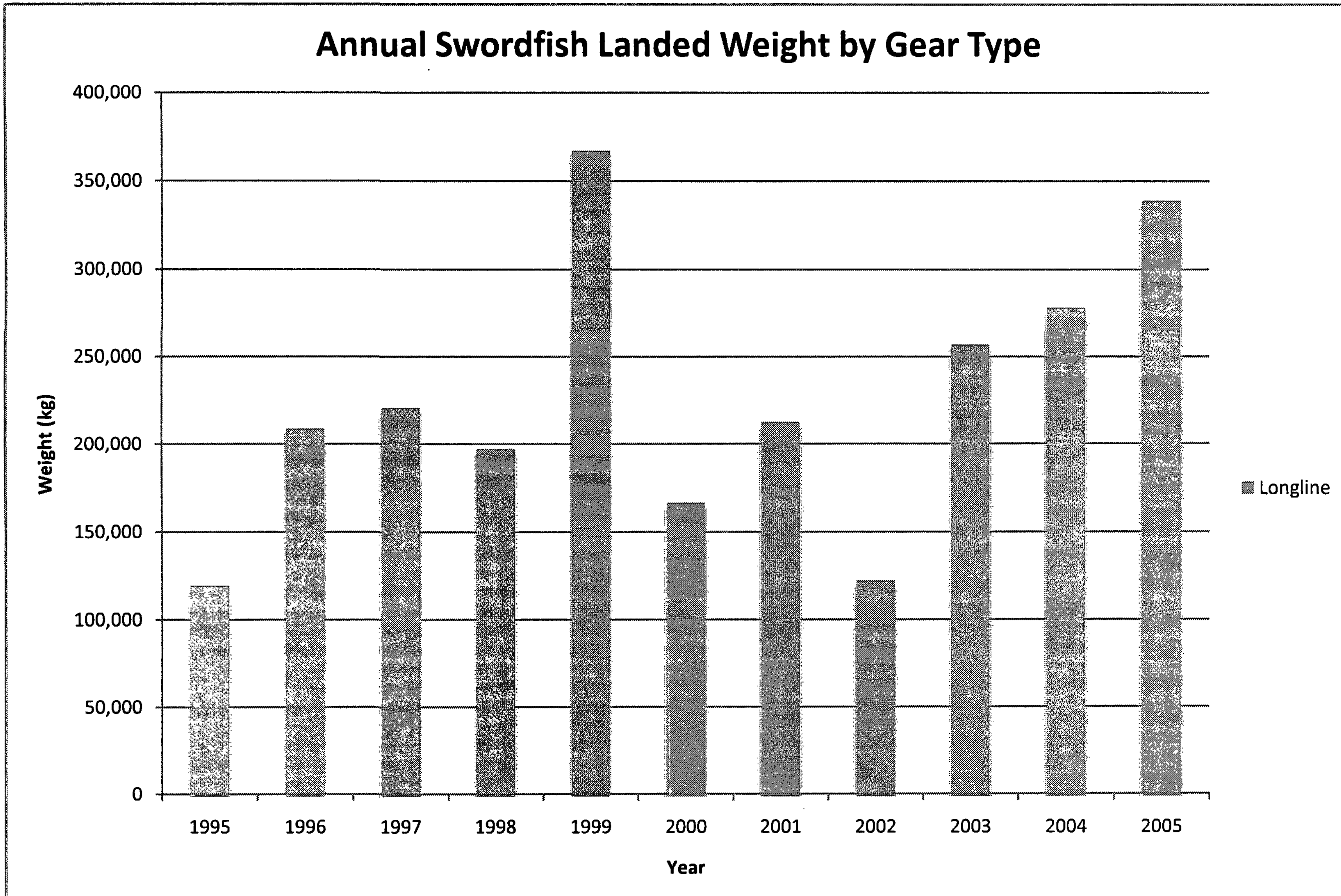

Figure A.6.17 Annual Swordfish Landed Weight by Gear Type. Years 1995-2005.

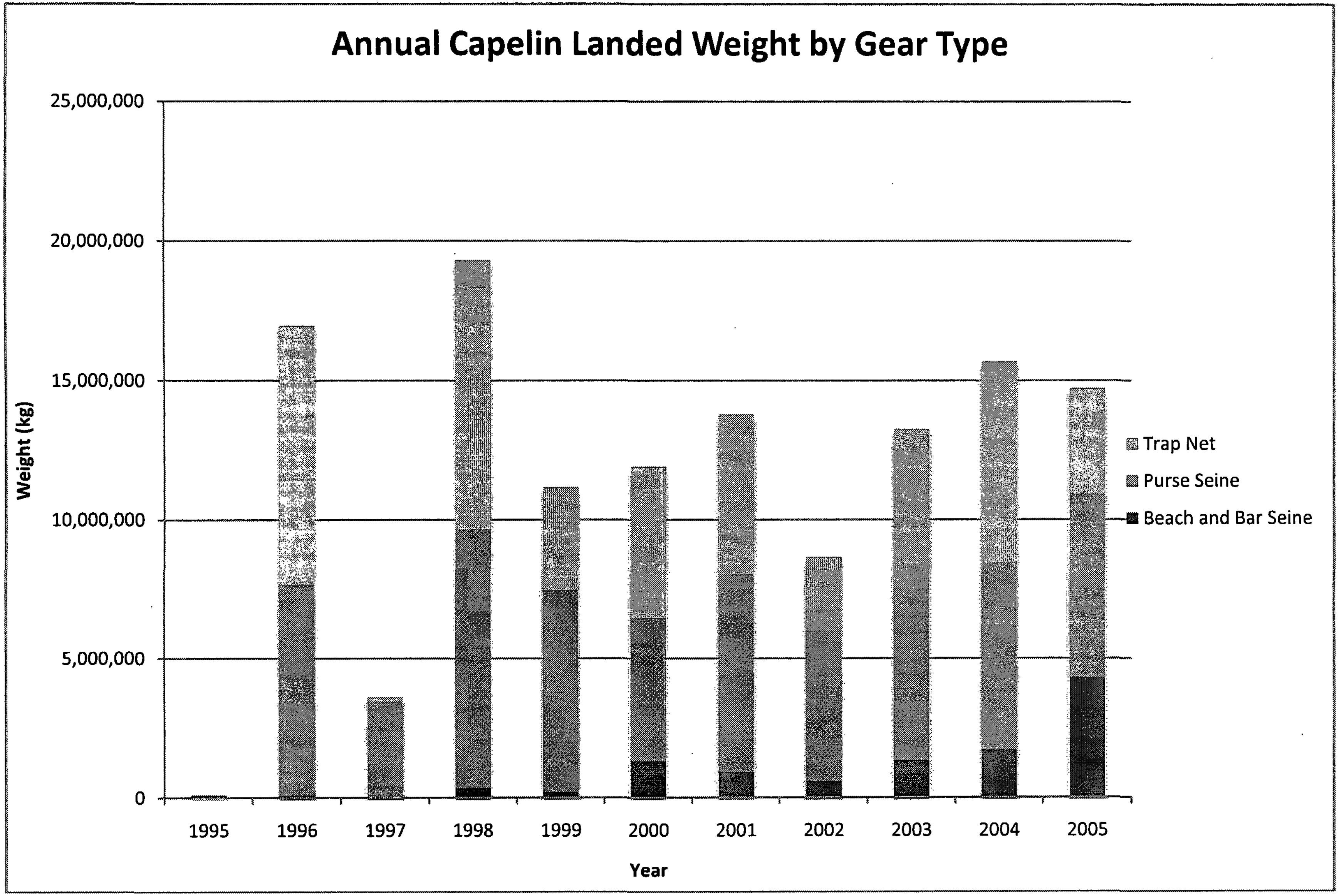

Figure A.6.18 Annual Capelin Landed Weight by Gear Type. Years 1995-2005.

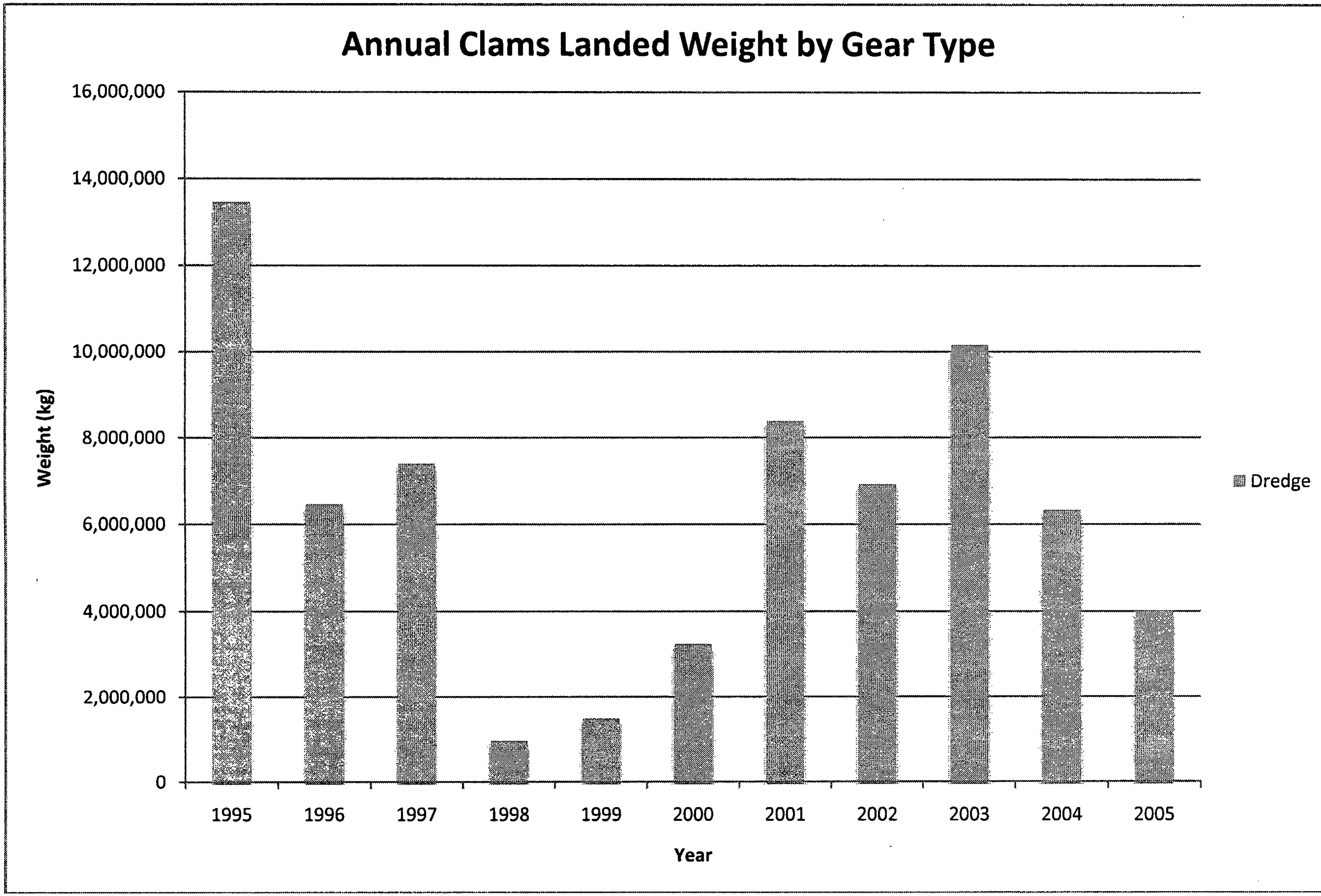

Figure A.6.19 Annual Clams Landed Weight by Gear Type. Years 1995-2005.

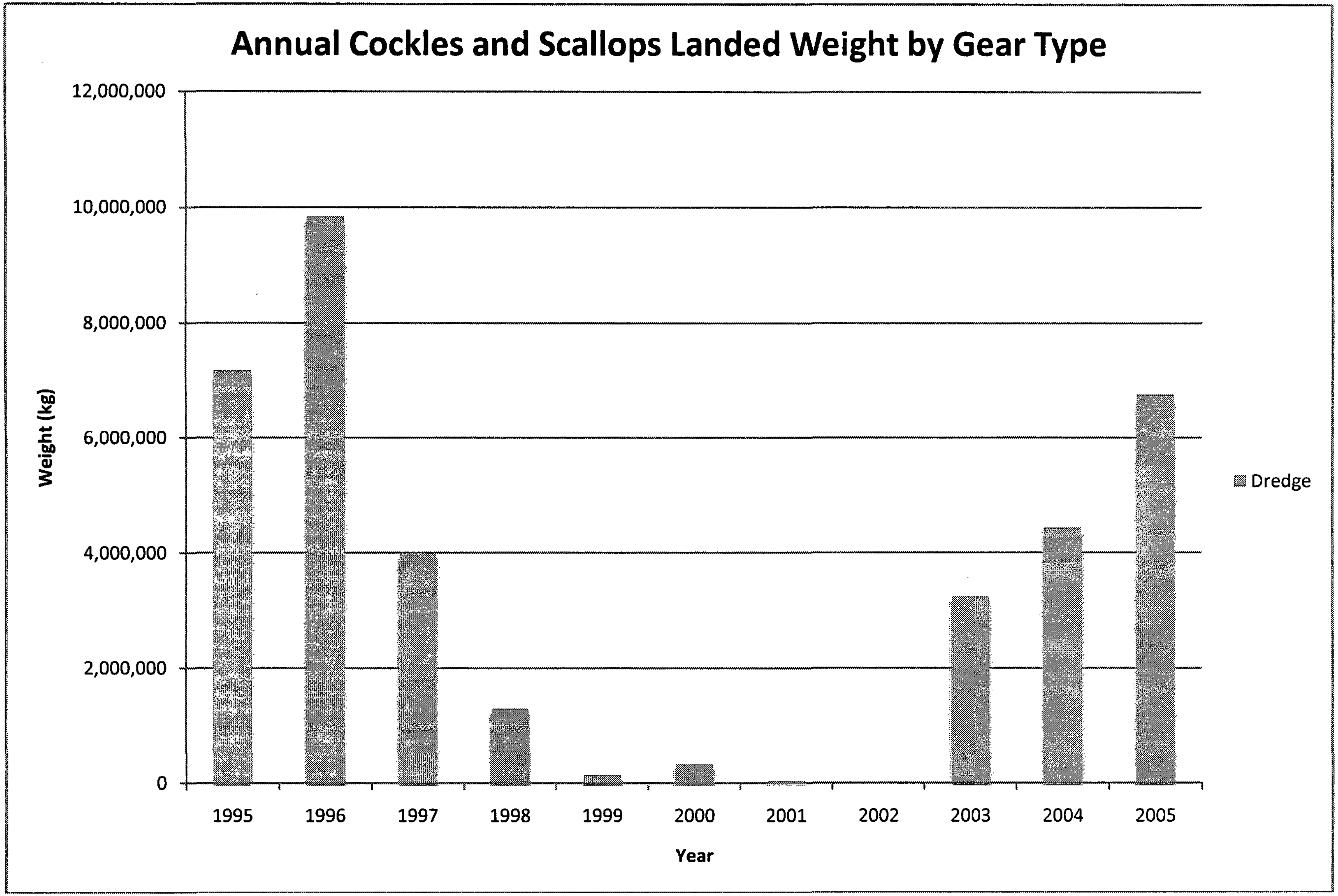

Figure A.6.20 Annual Cockles and Scallops Landed Weight by Gear Type. Years 1995-2005.

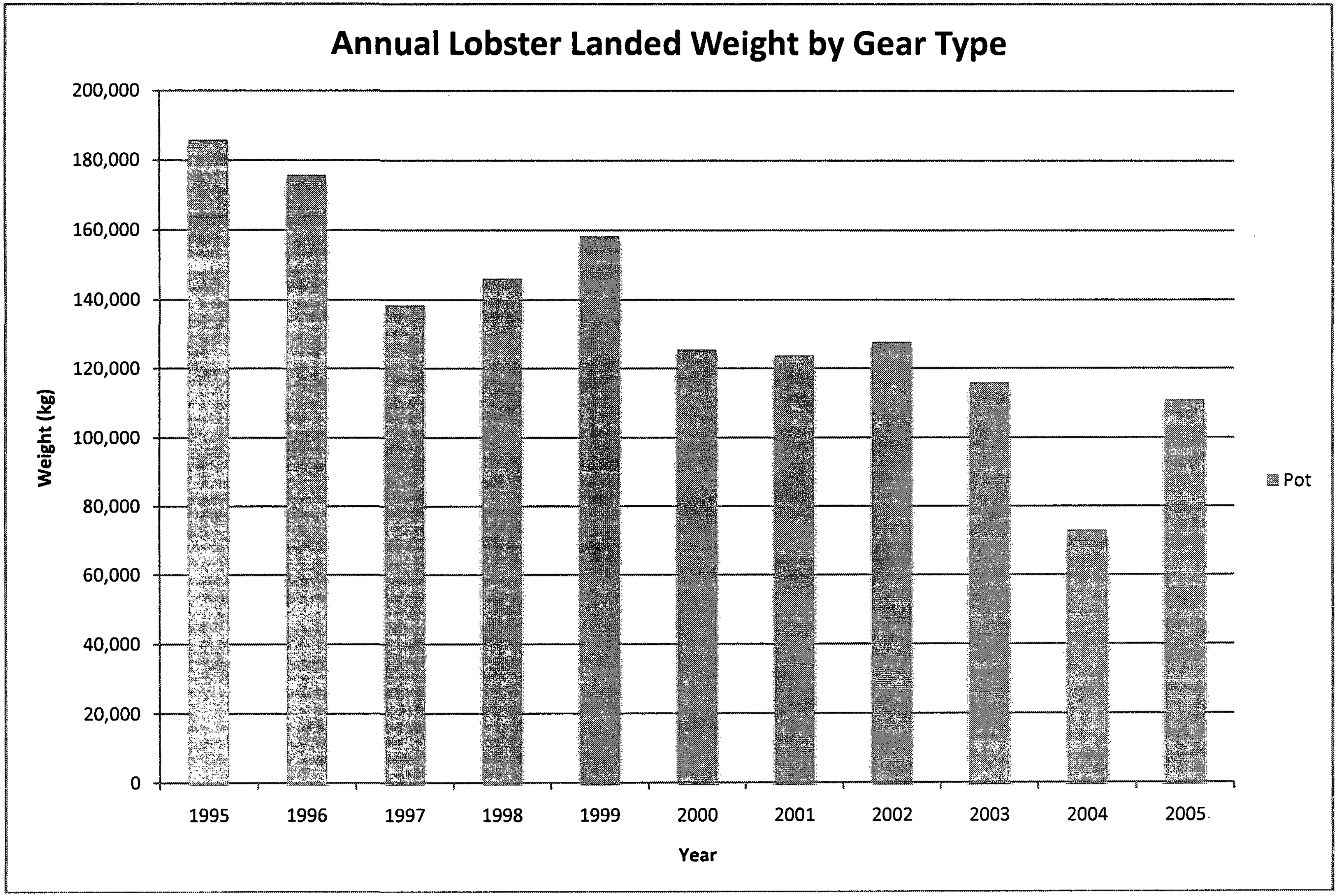

Figure A.6.21 Annual Lobster Landed Weight by Gear Type. Years 1995-2005.

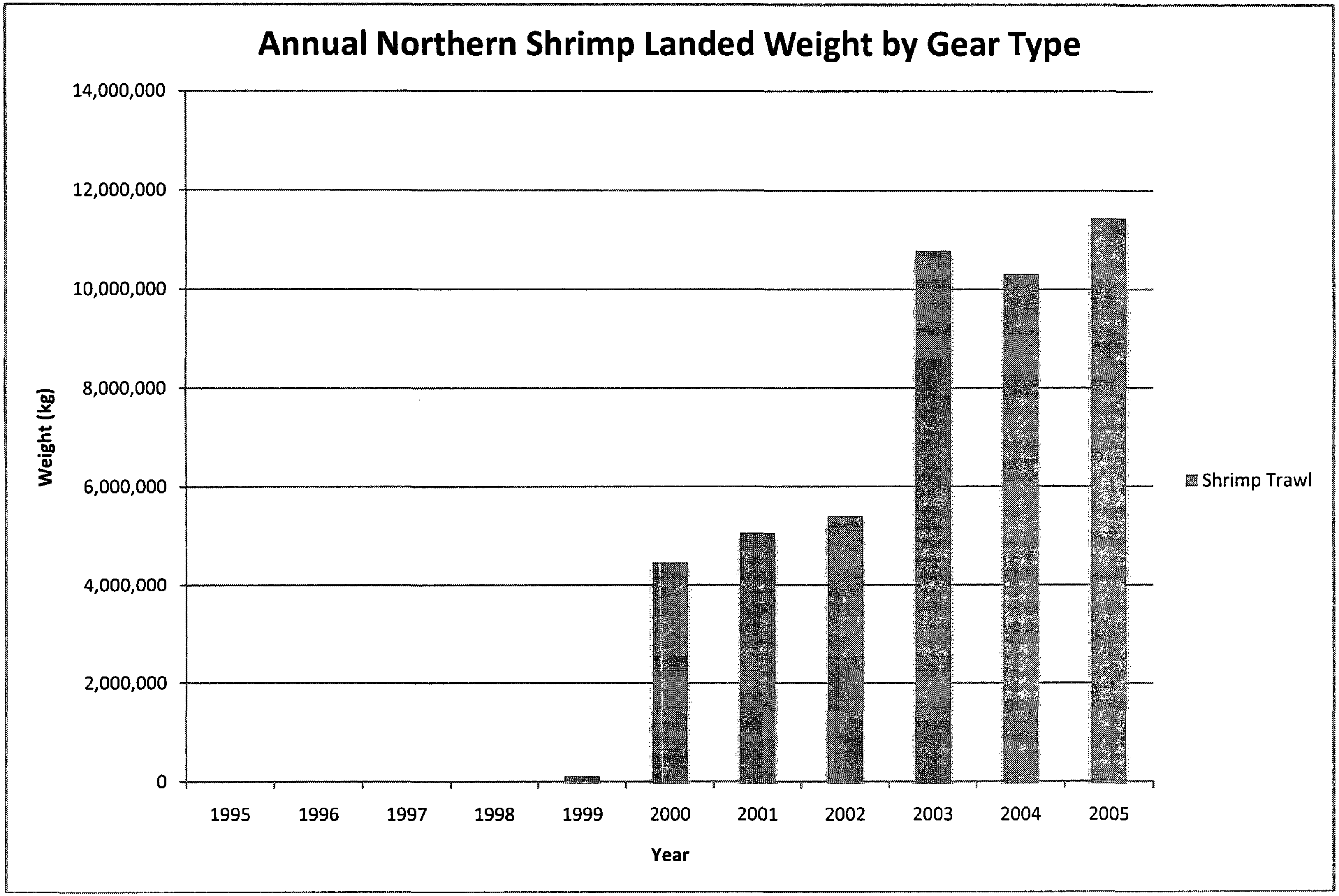

Figure A.6.22 Annual Northern Shrimp Landed Weight by Gear Type. Years 1995-2005.

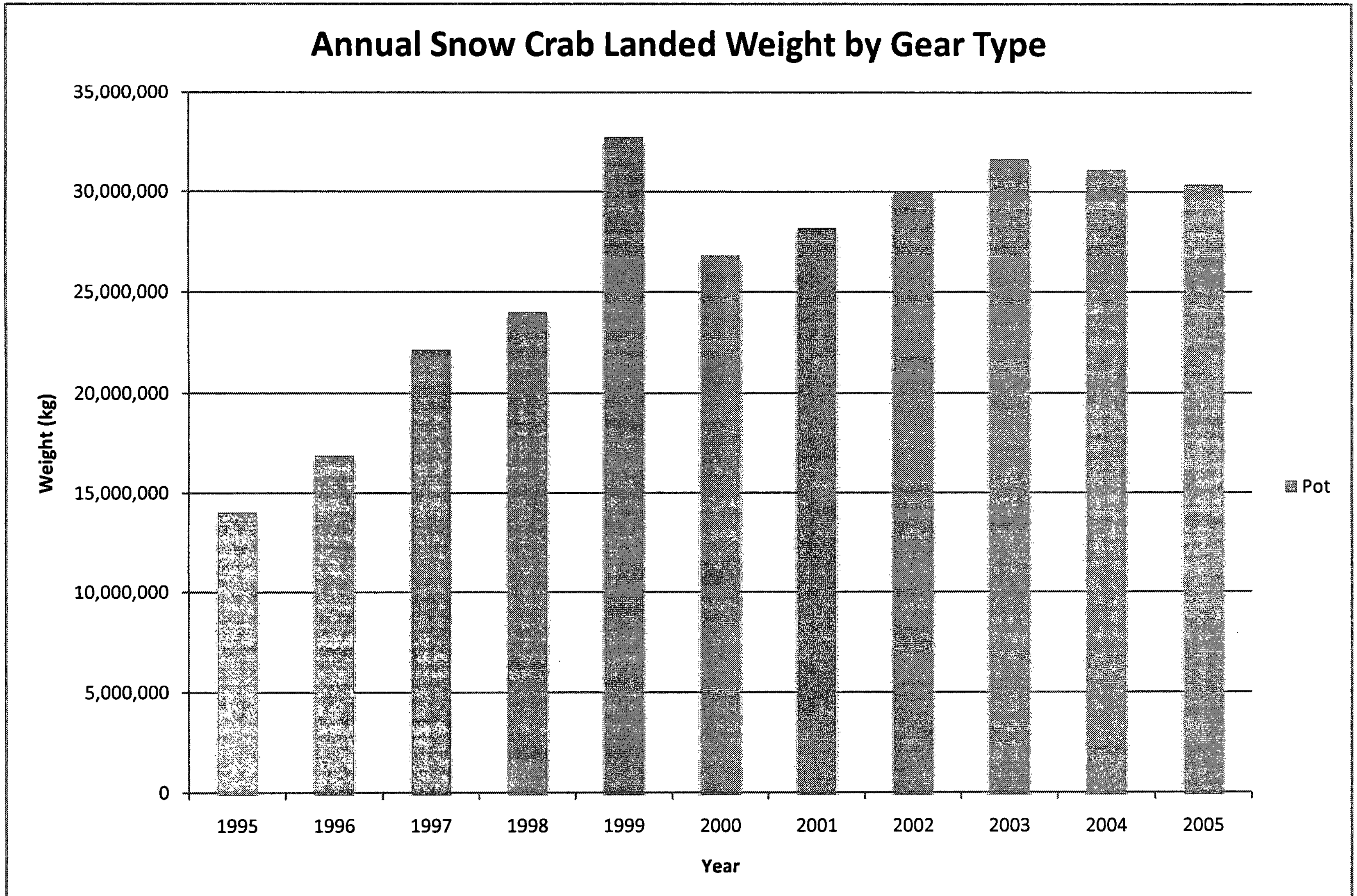

Figure A.6.23 Annual Snow Crab Landed Weight by Gear Type. Years 1995-2005.

A.6.3 Annual Catch by Species for each Gear Type

We continue our analysis of yearly landings by examining the relative proportions of each species caught for each gear type, e.g. the percentage of cod catches relative to the total landings of Bottom Otter Trawlers.Table A.2.1 shows the main species captured by each gear type.

Table A.6.2 Significant Species Captured by each Gear Type

Gear Type	Species
Bottom Otter Trawl	Cod, Redfish, American Plaice, Yellowtail Flounder, Greenland Halibut
Midwater Trawl	Cod, Redfish, American Plaice, Yellowtail Flounder
Shrimp Trawl	Northern Shrimp
Beach and Bar Seine	Capelin
Purse Seine	Capelin
Gillnet	Cod, Atlantic Halibut, American Plaice, Greenland Halibut, Monkfish, Lumpfish
Longline	Cod, Greenland Halibut, Swordfish
Handline	Cod
Trap Net	Capelin
Pot	Snow Crab, Lobster
Dredge	Clams, Cockles and Scallops

Some of the gear types are used to harvest one specific species, such as Shrimp Trawlers, whereas others are used to harvest a variety of species, notably gear types that prosecute groundfish, such as Bottom Otter Trawl as is illustrated in Figure A.6.24 below, one of the graphs showing the average annual catch by gear type for each species for gear types that a significant amount of more than one species.

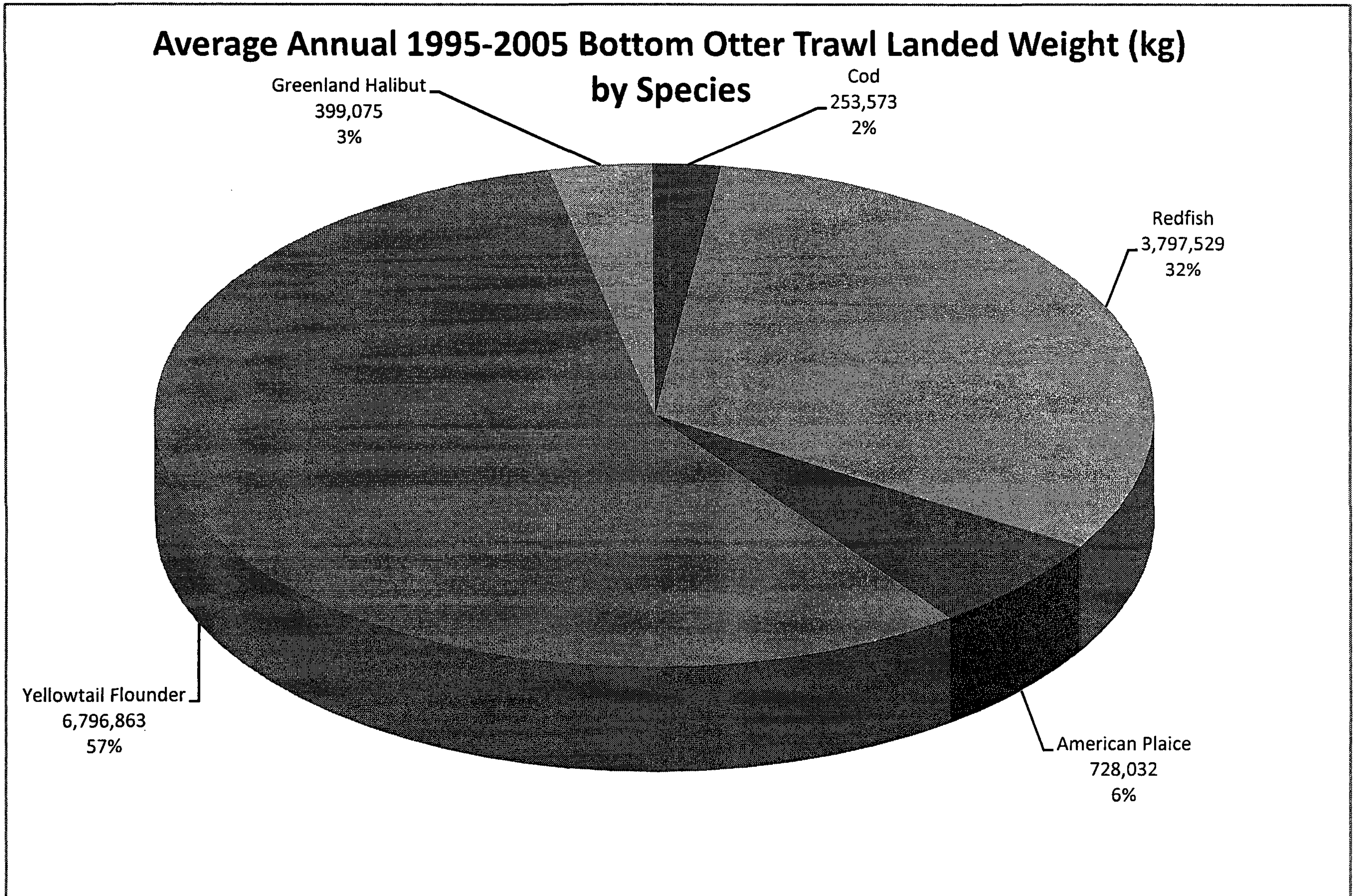

Figure A.6.24 Average Annual Bottom Otter Trawl Landed Weight by Species. Years 1995-2005.

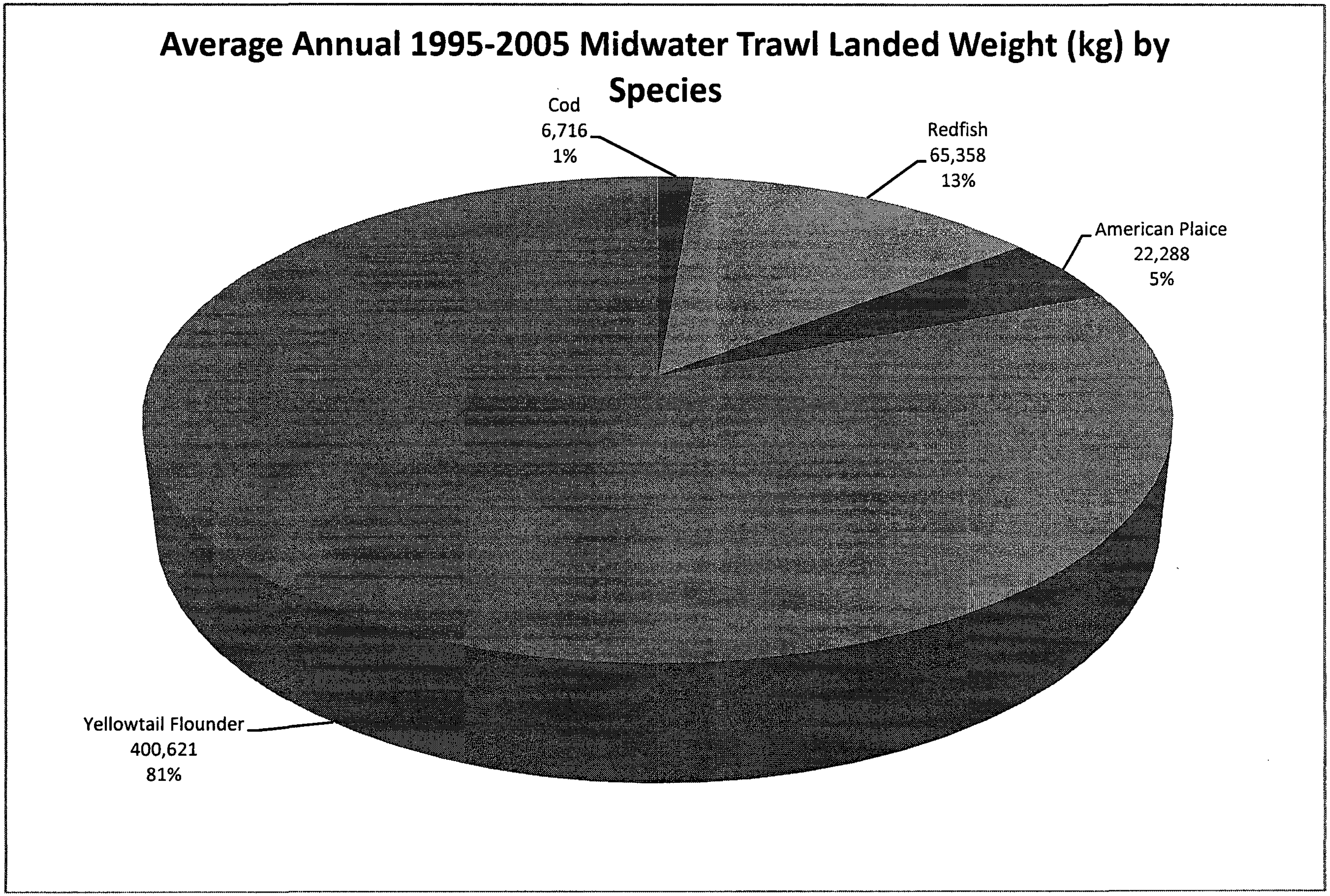

Figure A.6.25 Average Annual Midwater Trawl Landed Weight by Species. Years 1995-2005.

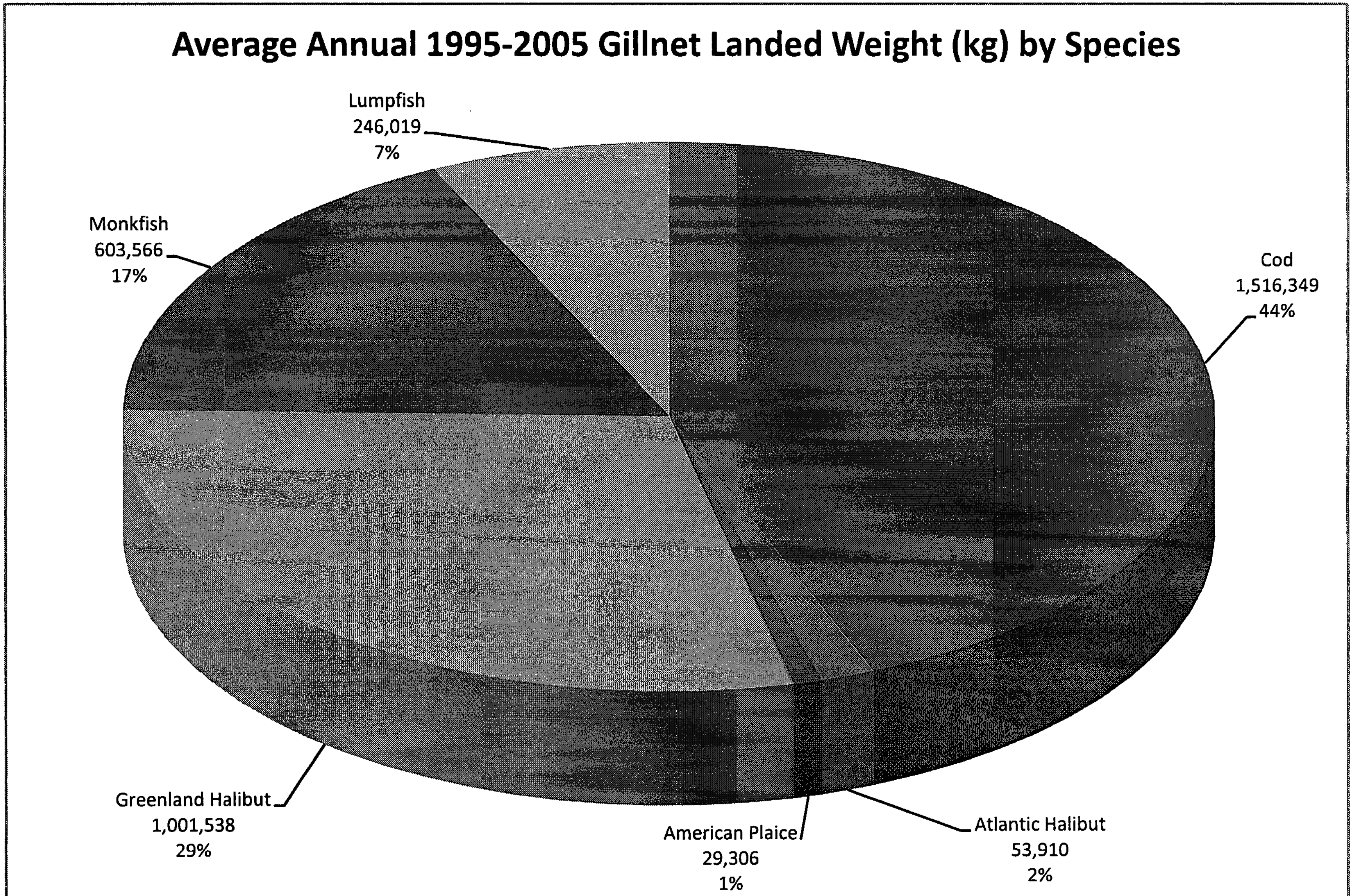

Figure A.6.26 Average Annual Gillnet Landed Weight by Species. Years 1995-2005.

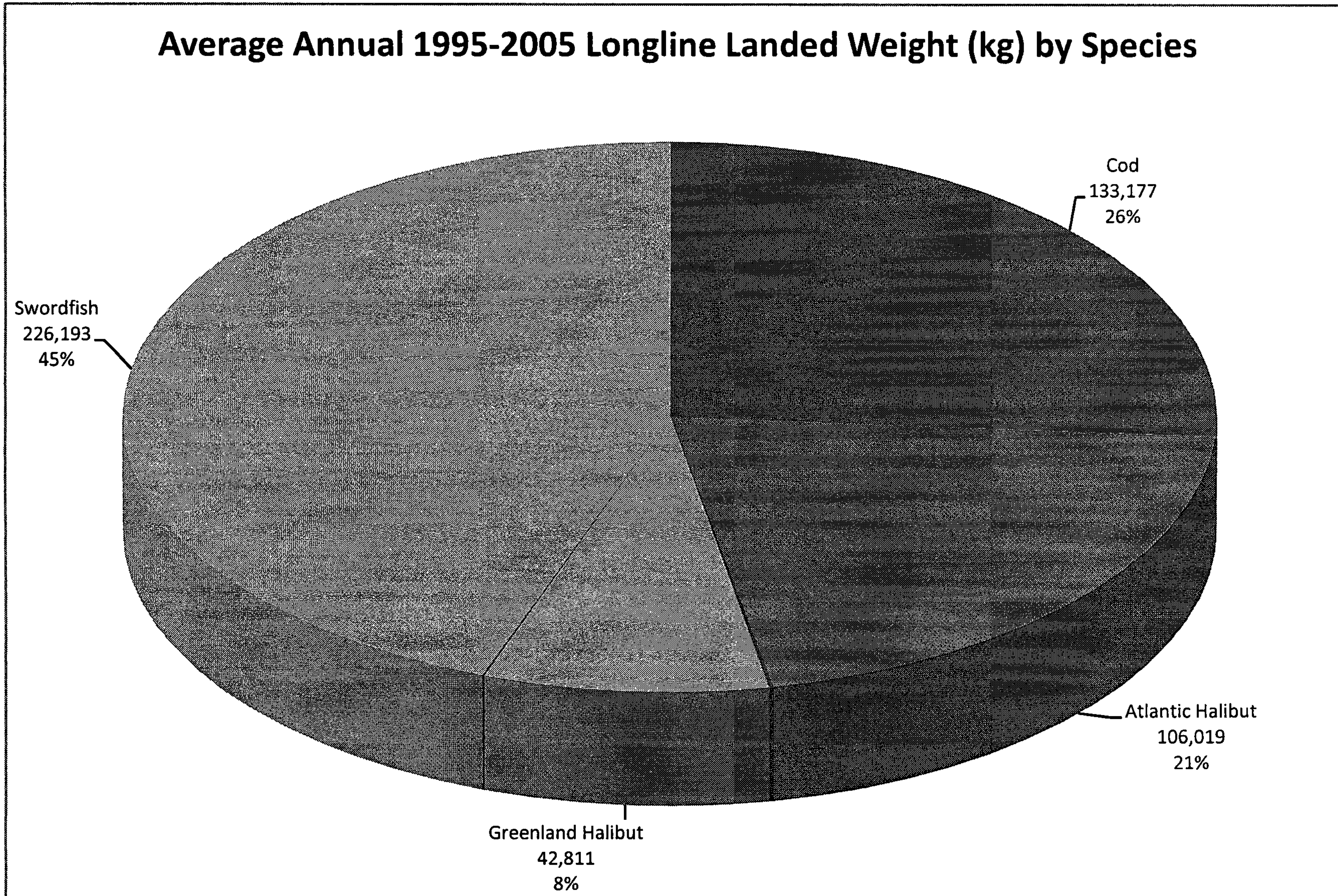

Figure A.6.27 Average Annual Longline Landed Weight by Species. Years 1995-2005.

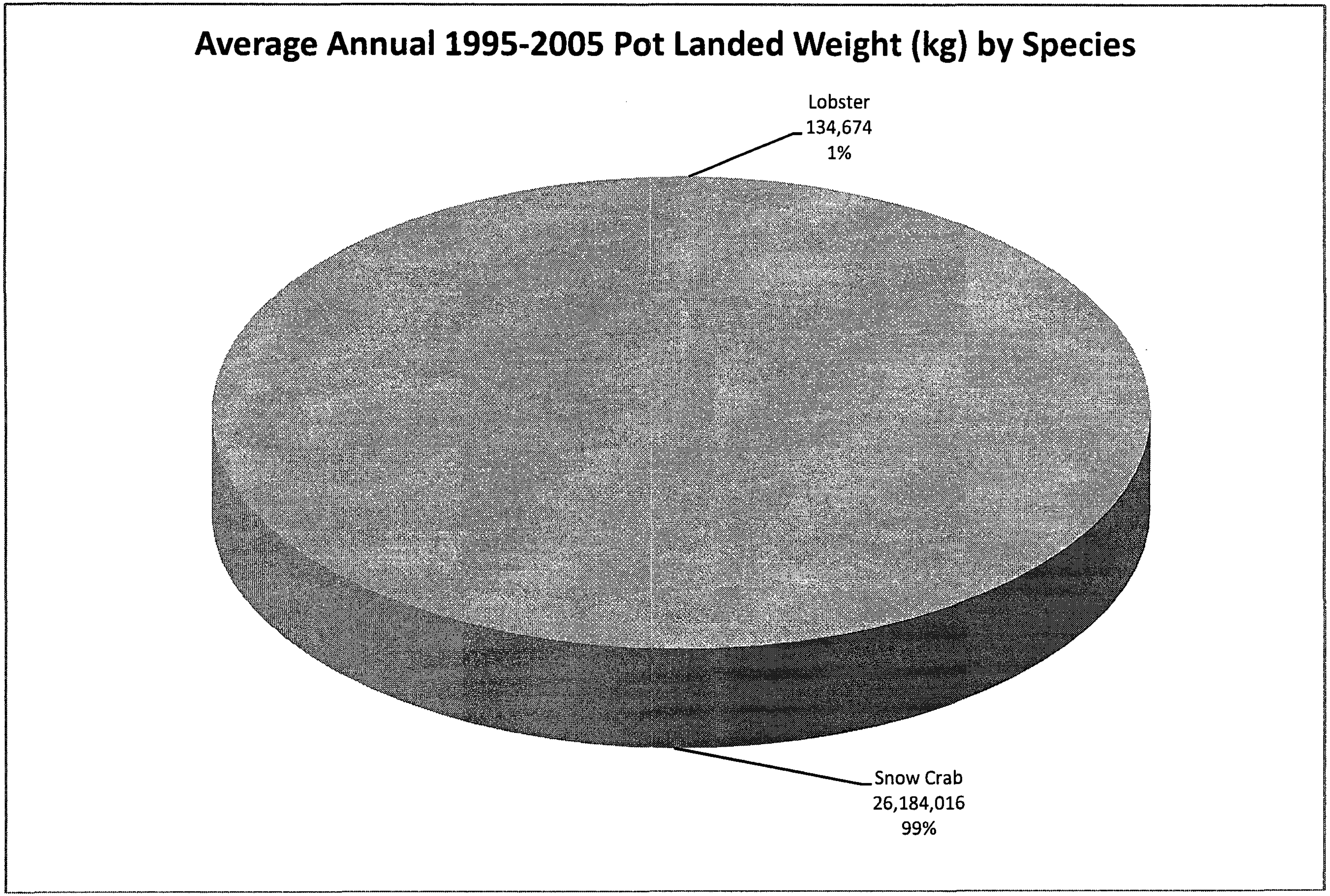

Figure A.6.28 Average Annual Pot Landed Weight by Species. Years 1995-2005.

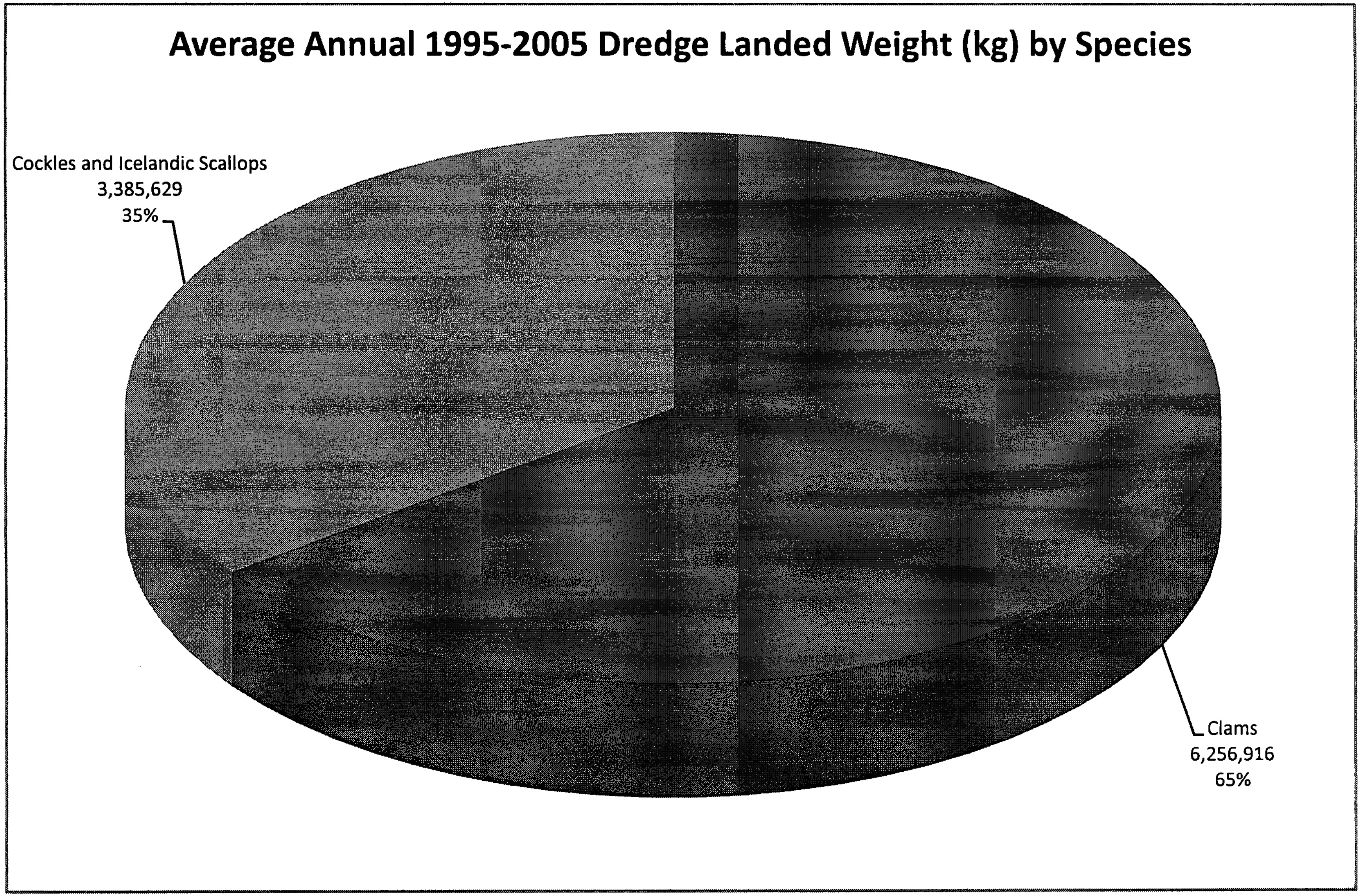

Figure A.6.29 Average Annual Dredge Landed Weight by Species. Years 1995-2005.

A.7 Further Data Filtering

In this section, we further our data filtering of the Grand Banks ZIFF dataset. Data filtering is carried out by the following steps:

- removal of Midwater Trawl as a gear type,
- exclusive use of data collected between 2000 to 2005 only,
- amalgamation of Clams, Cockles and Scallops into one species group (shellfish) and
- amalgamation of gear types that harvest Capelin only; Purse Seine, Beach and Bar Seine and Trap Net as one gear type.

These filtering decisions are analysed in further detail in the sections below.

A.7.1 Midwater Trawl

In 1999 there is a steep hike in catches of groundfish by Midwater trawl. A close examination of Yellowtail Flounder catches shows that, as a species, it is exclusively prosecuted by Bottom Otter Trawl in all years included in the study, excepting 1999 where just over 75% of total Yellowtail Flounder catches are captured by Bottom Otter Trawl. The remainder (25%) are recorded to be captured by Midwater trawl. This unexpected change could be explained if certain vessels in the fleet that would normally operate Bottom Otter Trawls switched to Midwater trawls for one year only (1999). Regardless of the cause, the portion of Midwater Trawl catches that show up in the ZIFF data, concerning average annual catches by species, originates from a single year, 1999, and is not representative of the typical gear type normally used to prosecute these species. This pattern of unusual Midwater Trawl catches in 1999 can also be clearly identified in the cases of Cod, Redfish, and American Plaice.

Midwater Trawl catches represent at most 6% of average annual catch by species when compared to other gear types. An examination of the figures of annual Midwater Trawl catches further illustrates the imbalance. Midwater Trawl catches reached a high of 4.9 thousand tonnes in 1999 which represents 92.7% of all Midwater trawl catches for the years 1995-2005, only to decrease to 41,734 kg in 2000 and zero for subsequent years. If we take into account the years 2000 to 2005, annual Midwater trawl catches average only 7 tonnes per year. This is not a significant amount compared to total annual catches and does not warrant inclusion as a significant gear type in our model, especially given the filtering of the years of interest as post-1999 (as described in the next section).

A.7.2 Using 2000-2005 data

The complete ZIFF dataset available for the Grand Banks analysis covers the years 1995-2005. However various major changes have taken place between 1995 and 1999 in the Grand Banks fisheries. Since the groundfish resource collapse and the subsequent moratorium of 1992, some fisheries have reopened and some stocks that were not previously harvested extensively have come under exploitation. For example, Yellowtail Flounder catches were nonexistent on the Grand Banks from 1995 to 1997 (in part due to the NAFO moratorium on this stock). Then, starting in 1998, close to 4,000 tonnes were landed. Catches remained between 9,000 and 12,000 tonnes from 2000 to 2005. Similarly, Shrimp catches only begin in earnest in 1999, becoming significant in the year 2000, where they accounted for 4 % of the total value of all landings in 3LNO.

Since the aim of this data analysis is to derive average values that are representative of the current situation, it is therefore logical to use data exclusively from the years 2000 to 2005 to drive the model as the pre-2000 period is clearly different from the post-2000 period for the reasons cited above.Table A.7.1below shows that the total cumulative value of the landings for the selected species account for 96.57% of all landings for the years 2000 to 2005.

Table A.7.1 Cumulative Total Landed Value. Years 2000-2005.

Cumulative total 2000-2005			
Species	Value	Percentage	Rank
Snow Crab	$762,734,788	69.79%	1
Northern Shrimp	$73,286,310	6.71%	2
Yellowtail Flounder	$54,679,056	5.00%	3
Clams	$39,145,910	3.58%	4
Cod	$19,939,366	1.82%	5
Capelin	$15,644,457	1.43%	6
Greenland Halibut	$15,022,091	1.37%	7
Cockles and Scallops	$14,069,224	1.29%	8
Redfish	$11,785,677	1.08%	9
Swordfish	$10,995,285	1.01%	10
Monkfish	$9,124,187	0.83%	11
Atlantic Halibut	$8,337,849	0.76%	12
Lobster	$7,973,852	0.73%	13
Lumpfish	$6,581,992	0.60%	14
American Plaice	$6,110,382	0.56%	15
Total	$1,055,430,426	96.57%	

Thus, for the purpose of developing a representative model of the Grand Banks fishery in the current period, we use average values from the more representative years 2000 to 2005.

A.7.3 Amalgamation of Clams, Cockles and Scallops as one Species for the Model

The spatial analysis of Cockles, Surf Clams and Icelandic Scallop catches by Dredge reveal that these are prosecuted in areas 3Na, 3Nb, and 3Nd, representing 45.1%, 8.3% and 45.7% of Clam catches and 29.5%, 18.7% and 50.0% of combined Cockles and Scallop catches, respectively (see Figure A.7.1). These three areas account for 99.1% of Clams and 98.2% of combined Cockles and Scallop catches. Furthermore, the time analysis of Dredge catches of Clams, Cockles and Scallop catches show similar dynamics (see Figure A.7.2.) Due to these marked similarities, these species are amalgamated for the purpose of developing the fisheries performance model for the Grand Banks fishery.

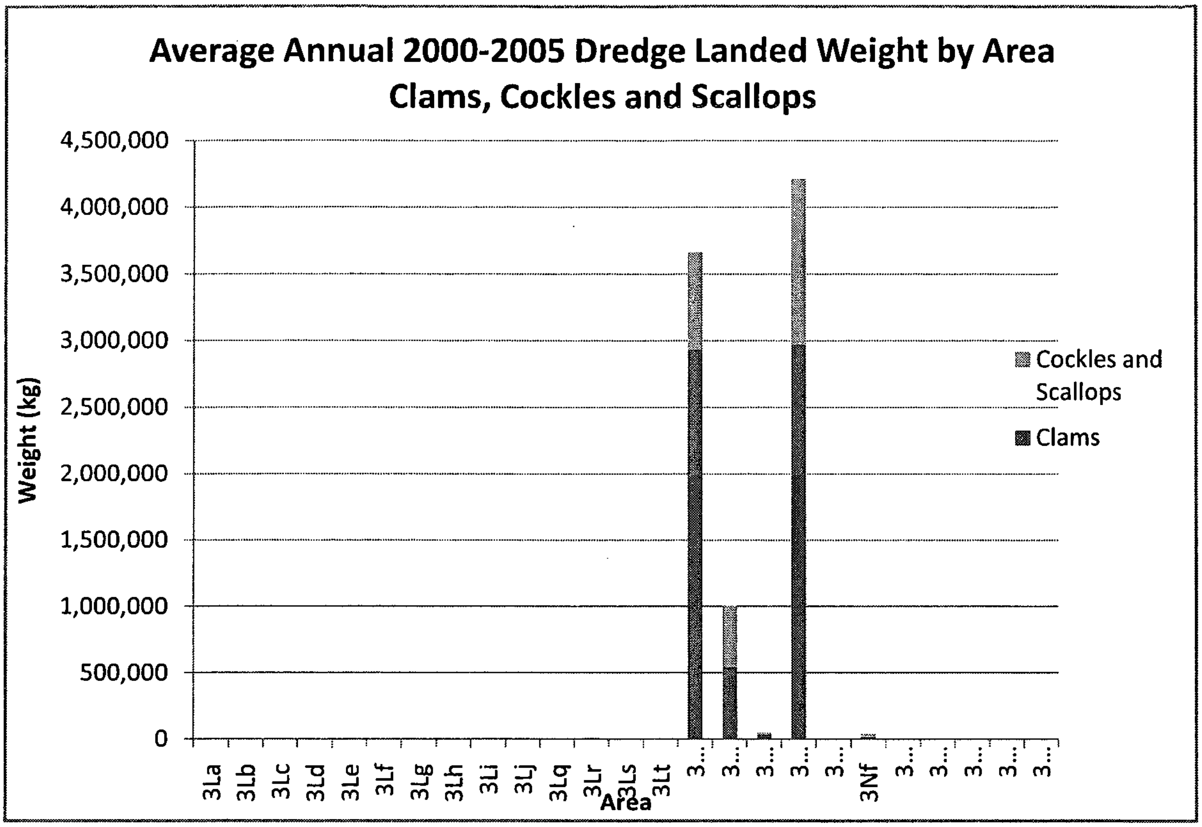

Figure A.7.1 Average Annual Dredge Landed Weight by Area – Clams, Cockles and Scallops. Years 2000-05.

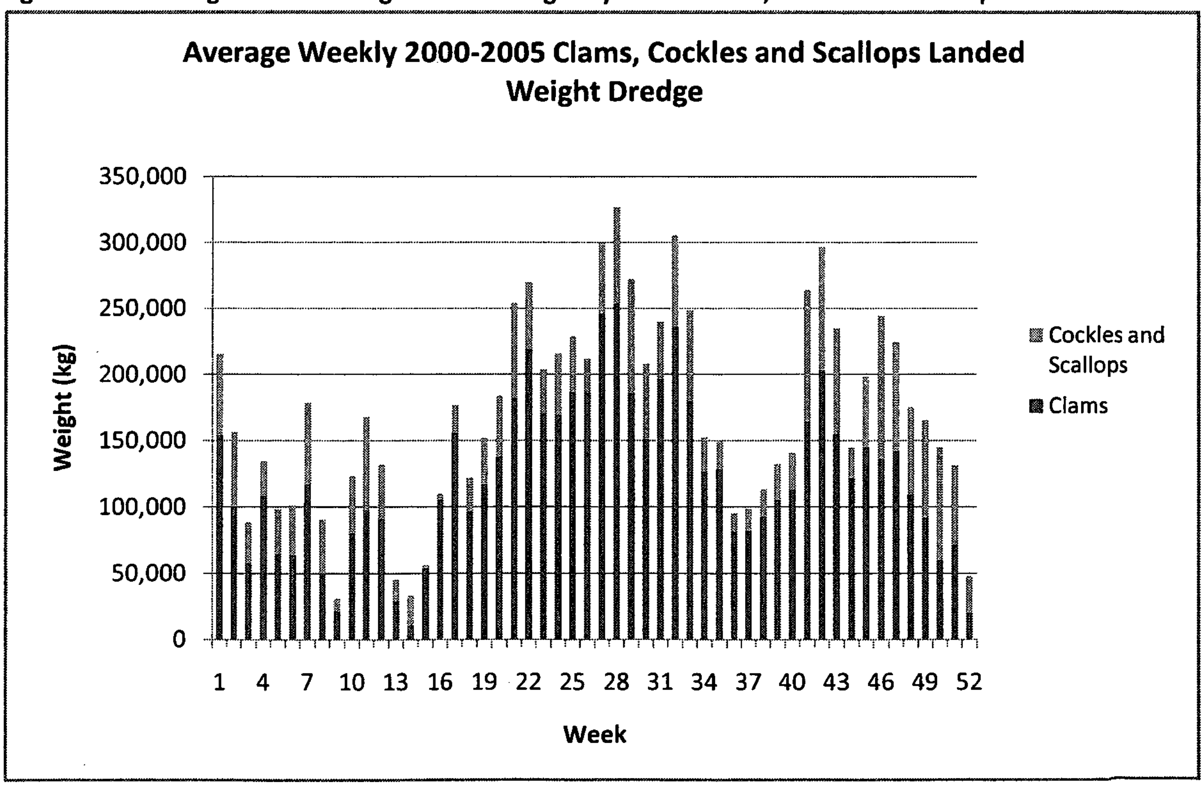

Figure A.7.2 Average Weekly Dredge Landed Weight by Areas. Clams, Cockles and Scallops. Years 2000-05

A.7.4 Amalgamation of Beach and Bar Seine, Purse Seine and Trap Net as one Gear Type for the Model

Average annual catches in the years 2000 to 2005 by Beach and Bar Seine, Purse Seine and Trap net of Capelin account for 100%, 100% and 99% of total catches by each of these gear types, respectively. As illustrated in Figure A.7.3 and Figure A.7.4, these three gear types are used in the same areas (3La, 3Lb and 3Lf), and at the same time of year. Given these similarities, these three gear types are considered as one gear exploiting the Capelin species for the model.

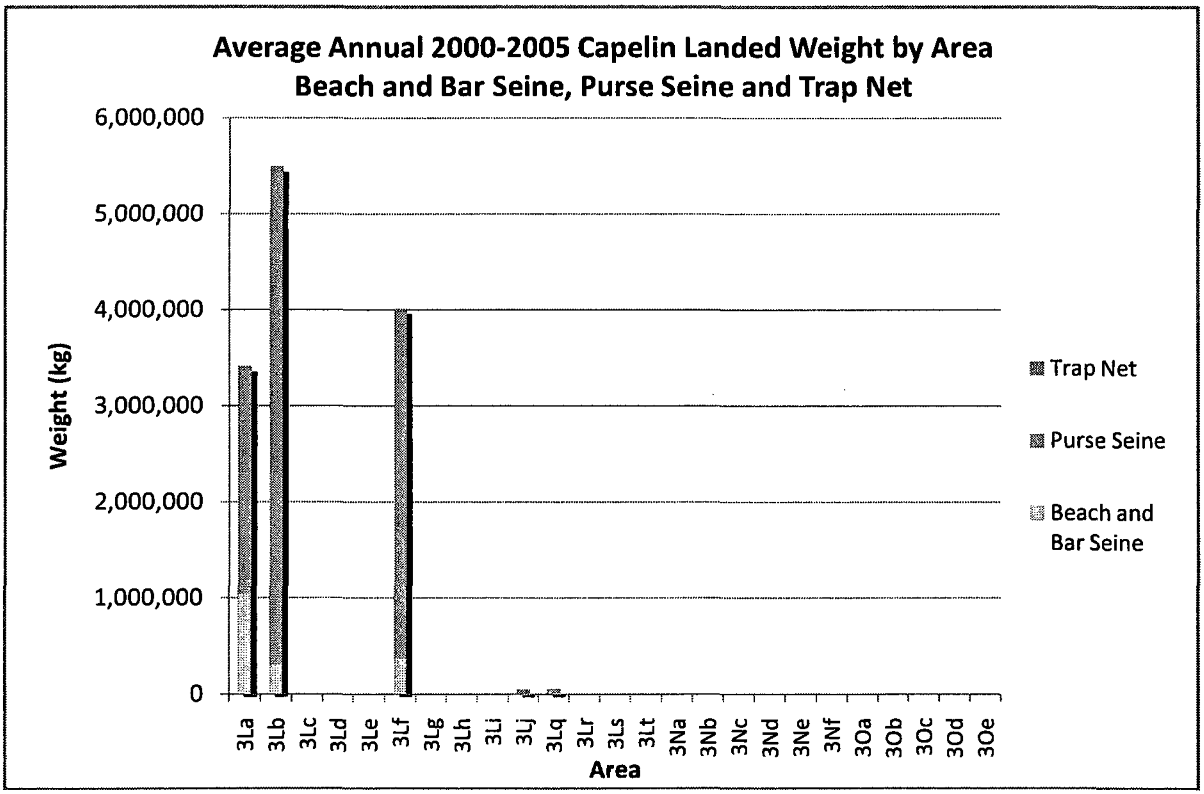

Figure A.7.3 Average Annual Capelin Landed Weight by Area - Beach and Bar Seine, Purse Seine and Trap Net. Years 2000-2005.

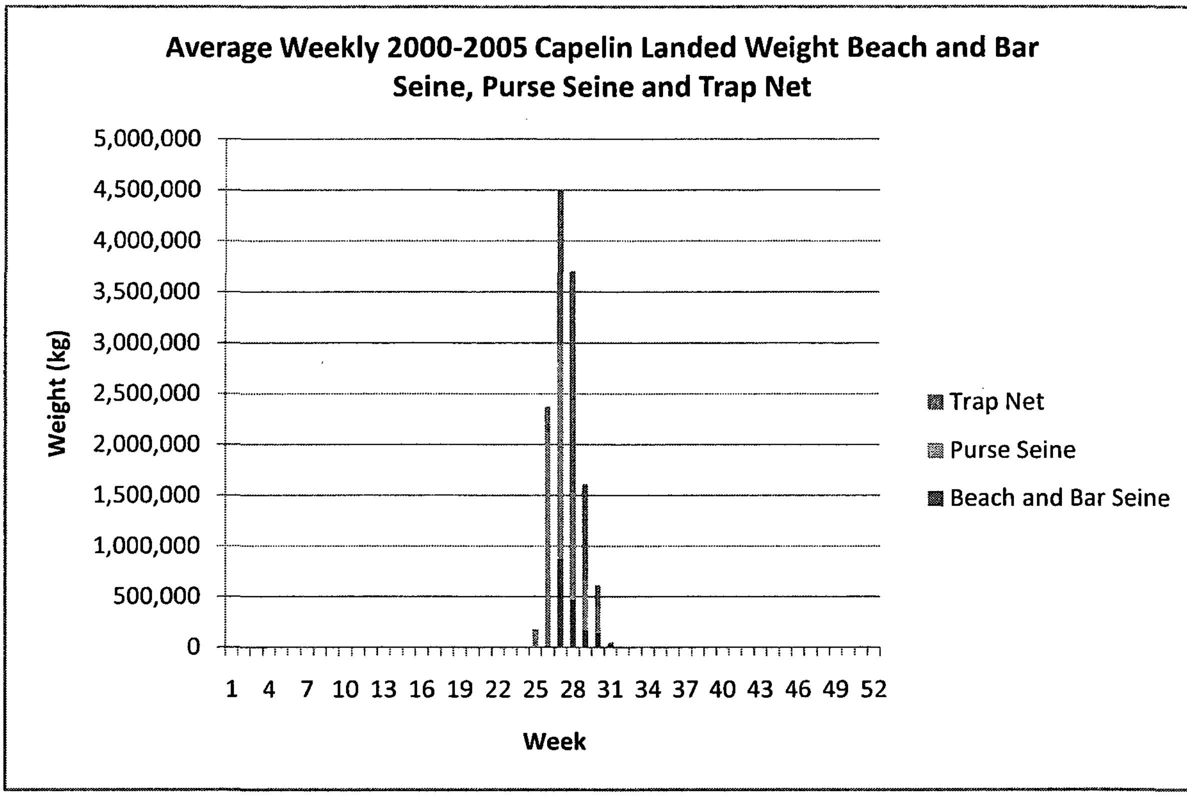

Figure A.7.4 Average Weekly 2000-2005 Capelin Landed Weight - Beach and Bar Seine, Purse Seine and Trap Net

The adjustments described in subsectionsA.7.1, A.7.2, A.7.3 and A.7.4result in a parsimonious number of species and gear types combinations without loss of pertinent information for describing the Grand Banks fleet activity and performance. We use this filtered dataset to identify the significant species and gear type combinations as described in the next section.

A.8 Identification of Species and Gear Type Combinations

Significant species and gear types combinations are selected by examining two sets of indicators, namely:

1. The proportion that each gear type represents of the total catch by species, and
2. The proportion that each species represents of the total catch by gear type.

Table A.8.1. contains the information on the average annual catch for each species and gear type combination and this information is used to compute the two sets of indicators contained in Table A.8.2 andTable A.8.3.Table A.8.2 below shows the average annualpercentage of the total catch by species that each gear type contributesand Table A.8.3displays the proportion of average annual catch by gear type that each species represents. Finally, Table A.8.4lists the significant gear type and species combinations for the Grand Banks data used in the thesis.

Table A.8.1 Average Annual Catch per Species and Gear Type. Years 2000-2005.

	Average Annual 2000-2005 Catch per Species and Gear Type								
	Bottom Otter Trawl	Shrimp Trawl	BB and P Seine, T Net	Gillnet	Longline	Hand Line	Pot	Dredge	Total
Cod	406,998	0	60,097	1,604,952	128,880	311,805	0	0	2,512,731
Redfish	3,572,364	1	0	1,694	0	40	0	0	3,574,099
Atlantic Halibut	12,772	0	0	64,126	122,777	0	0	0	199,674
American Plaice	1,276,459	0	0	28,818	174	12	0	0	1,305,461
Yellowtail Flounder	11,620,019	0	0	3,539	0	0	0	0	11,623,557
Greenland Halibut	726,658	0	0	1,158,001	67,766	29	0	0	1,952,453
Monkfish	7,335	0	0	967,390	547	0	0	0	975,272
Lumpfish	0	0	0	262,807	0	0	1	0	262,808
Swordfish	31	0	0	85	229,135	0	0	0	229,250
Capelin	0	0	13,013,829	0	0	0	0	0	13,013,829
Clams, Cockles and Scallops	0	0	0	0	0	0	0	8,974,878	8,974,878
Lobster	0	0	0	0	0	0	112,848	0	112,848
Northern Shrimp	0	7,907,508	0	0	0	0	0	0	7,907,508
Snow Crab	0	0	0	2	0	0	29,697,958	0	29,697,960
Total	17,622,633	7,907,510	13,073,926	4,091,412	549,277	311,886	29,810,807	8,974,878	82,342,328

Table A.8.2 Average Annual Catch –Percentage of total Species Catch by Gear Type. Years 2000-2005.

Average Annual 2000-2005 Percentage of Total Catch by Species for each Gear Type									
	Bottom Otter Trawl	Shrimp Trawl	BB and P Seine, T Net	Gillnet	Longline	Hand Line	Pot	Dredge	Total
Cod	16%	0%	2%	64%	5%	12%	0%	0%	100%
Redfish	100%	0%	0%	0%	0%	0%	0%	0%	100%
Atlantic Halibut	6%	0%	0%	32%	61%	0%	0%	0%	100%
American Plaice	98%	0%	0%	2%	0%	0%	0%	0%	100%
Yellowtail Flounder	100%	0%	0%	0%	0%	0%	0%	0%	100%
Greenland Halibut	37%	0%	0%	59%	3%	0%	0%	0%	100%
Monkfish	1%	0%	0%	99%	0%	0%	0%	0%	100%
Lumpfish	0%	0%	0%	100%	0%	0%	0%	0%	100%
Swordfish	0%	0%	0%	0%	100%	0%	0%	0%	100%
Capelin	0%	0%	100%	0%	0%	0%	0%	0%	100%
Clams, Cockles and Scallops	0%	0%	0%	0%	0%	0%	0%	100%	100%
Lobster	0%	0%	0%	0%	0%	0%	100%	0%	100%
Northern Shrimp	0%	100%	0%	0%	0%	0%	0%	0%	100%
Snow Crab	0%	0%	0%	0%	0%	0%	100%	0%	100%

Table A.8.3Average Annual Catch – Percentage of total Gear catches by species. Years 2000-2005.

	Average Annual 2000-2005 Catch per Species and Gear Type						
	Cod	Redfish	Atlantic Halibut	American Plaice	Yellowtail Flounder	Greenland Halibut	Monkfish
Bottom Otter Trawl	2%	20%	0%	7%	66%	4%	0%
Shrimp Trawl	0%	0%	0%	0%	0%	0%	0%
BB and P Seine, T Net	0%	0%	0%	0%	0%	0%	0%
Gillnet	39%	0%	2%	1%	0%	28%	24%
Longline	23%	0%	22%	0%	0%	12%	0%
Hand Line	100%	0%	0%	0%	0%	0%	0%
Pot	0%	0%	0%	0%	0%	0%	0%
Dredge	0%	0%	0%	0%	0%	0%	0%

Table A.8.3 Continued

	Swordfish	Capelin	Clams, Cockles and Scallops	Lobster	Northern Shrimp	Snow Crab	Lumpfish	Total
Bottom Otter Trawl	0%	0%	0%	0%	0%	0%	0%	100%
Shrimp Trawl	0%	0%	0%	0%	100%	0%	0%	100%
BB and P Seine, T Net	0%	100%	0%	0%	0%	0%	0%	100%
Gillnet	0%	0%	0%	0%	0%	0%	6%	100%
Longline	42%	0%	0%	0%	0%	0%	0%	100%
Hand Line	0%	0%	0%	0%	0%	0%	0%	100%
Pot	0%	0%	0%	0%	0%	100%	0%	100%
Dredge	0%	0%	100%	0%	0%	0%	0%	100%

Table A.8.4 Significant Species and Gear Types Combinations

Bottom Otter Trawl	Cod
	Redfish
	Atlantic Halibut
	American Plaice
	Yellowtail Flounder
	Greenland Halibut
Shrimp Trawl	Northern Shrimp
Beach and Bar Seine, Purse Seine and Trap Net	Capelin
Gillnet	Cod
	Atlantic Halibut
	American Plaice
	Greenland Halibut
	Monkfish
	Lumpfish
Longline	Cod
	Atlantic Halibut
	Greenland Halibut
	Swordfish
Handline	Cod
Pot	Lobster
	Snow Crab
Dredge	Clams, Cockles and Scallops

A.9 Significant species and Gear Type combination catches by area

Section A.4 of this text contains a spatial analysis by species and gear types for the NAFO divisions 3L, 3N and 3O. Each of these divisions are divided into subdivisions identified by a letter suffix, i.e. 3L is divided into 3La, 3Lb, 3Lc, etc...(See Figure A.12.2).These subdivisions are referred to as unit areas or units. Because the original data contain information on the origin of the catch by subdivision (See Table A.1.1), the spatial analysis can be refined to include catches by subdivisions and unit areas. The analysis can also be refined using the species and gear type combinations identified previously.

Table A.9.1 summarizes the main harvesting areas for each selected species and gear type combination, as determined by the percentage of the catch weight by subdivision relative to the total for all areas. Those areas accounting for 2% or more of the total catch are selected and presented in this table.

Table A.9.1Percentage of Total Catch by Area, for each Significant Species and Gear Types Combinations

Percentage of Total Catch by Area														
Gear Type	**Species**	3La	3Lb	3Lc	3Ld	3Le	3Lf	3Lg	3Lh	3Li	3Lj	3Lq	3Lr	3Ls
Bottom Otter Trawl	Cod													
	Redfish													
	Atlantic Halibut				2%									
	American Plaice				6%								3%	
	Yellowtail Flounder												3%	
	Greenland Halibut				100%									
Shrimp Trawl	Northern Shrimp			5%	7%	21%				66%				
BB Seine, P Seine and T Net	Capelin	26%	42%				31%							
Gillnet	Cod	36%	37%				9%				8%	7%		
	Atlantic Halibut													
	American Plaice	12%	15%	23%	19%		4%							
	Greenland Halibut	7%	12%	18%	27%	18%								
	Monkfish													
	Lumpfish	49%	29%				18%					3%		
Longline	Cod	14%	8%				4%				7%	8%		
	Atlantic Halibut													
	Greenland Halibut									2%				
	Swordfish													
Handline	Cod	11%	52%				12%				21%	5%		
Pot	Lobster	76%	15%				6%					3%		
-	Snow Crab	4%	4%	14%	7%		4%	12%	7%	10%	5%	4%		
Dredge	Clams, Cockles and Scallops													

Table A.9.1 Continued

Gear Type	Species	3Lt	3Na	3Nb	3Nc	3Nd	3Ne	3Nf	3Oa	3Ob	3Oc	3Od	3Oe
Bottom Otter Trawl	Cod		3%		31%					15%	3%	40%	5%
	Redfish								4%		33%	9%	53%
	Atlantic Halibut				30%				5%		26%	12%	24%
	American Plaice		19%		43%					9%		18%	
	Yellowtail Flounder		18%		57%					8%		14%	
	Greenland Halibut												
Shrimp Trawl	Northern Shrimp												
BB Seine, P Seine and T Net	Capelin												
Gillnet	Cod												
	Atlantic Halibut								8%		52%	17%	23%
	American Plaice										5%	3%	16%
	Greenland Halibut										12%		6%
	Monkfish								9%		33%	36%	22%
	Lumpfish												
Longline	Cod				6%				9%		4%	21%	16%
	Atlantic Halibut	4%			33%			2%	9%		14%	15%	20%
	Greenland Halibut										41%		50%
	Swordfish					8%		8%			27%	8%	47%
Handline	Cod												
Pot	Lobster												
	Snow Crab	8%		7%			2%		2%	3%			
Dredge	Clams, Cockles and Scallops		41%	11%		47%							

The main harvesting areas are identified in Table A.9.1. using a percentage of total catch for each species and gear type combinations. The graphics below also show the weight that the percentage figures in the table correspond to.

The first distinction that can be made is whether the gear types operate inshore or offshore. Here we define as inshore the NAFO subdivisions that are adjacent to the coast, i.e. 3La, 3Lb, 3Lf, 3Lj, and 3Lq in our area of study.
Most gear types operate in only three to five subdivisions, except for gillnet and Pot, both of which operate inshore and offshore, and Pot catches of Crab occur in all but five of the twenty-five subdivisions included in the study.

- All of Bottom Otter Trawl activity occurs offshore and is mostly concentrated on the southern tip of the Grand Banks, in subdivisions 3Na and 3Nc and in 3O, except for Greenland Halibut that is only harvested in 3Ld and Redfish in 3O. Small portions of Atlantic Halibut and American Plaice total catch also occur in 3Ld, although it can be interpreted as bycatch of the Greenland Halibut harvest. Yellowtail Flounder catches represent more than half of all Bottom Otter Trawl Catches. American Plaice and Cod Catches closely resemble that of Yellowtail Flounder and can also be interpreted as bycatch.

- Shrimp Trawlers operate on the Northeastern edge of the Grand Banks. Two thirds of Northern Shrimp overall landings take place in subdivision 3Li, two fifths in 3Le and the remainder in 3Lc and 3Ld.

- Capelin landings by Beach and Bar Seine, Purse Seine, Trap Net and Hand Line is limited to 3La, 3Lb and 3Lf corresponding to Bonavista Bay, Trinity Bay and Conception Bay, respectively.

- Gillnet activity can be split in two categories; a segment covering all inshore subdivisions and another segment offshore in 3Oa, 3Oc, 3Od and 3Oe on the southwest edge of the

Grand Banks. Cod and Lumpfish are captured in all inshore areas, while Atlantic Halibut and Monkfish are captured by the offshore segment of the gillnet fleet. Both the offshore and the inshore Gillnet fleet harvest Greenland Halibut and American Plaice Catches in their respective areas of operations indicated above.

- Longline is used inshore along the coast to catch Cod, and offshore on the southwest edge of the Grand Banks to catch Cod as well as Atlantic Halibut, Greenland Halibut, and Swordfish. However, some activity is also observed on the southeast portion targeting Swordfish, Atlantic Halibut and Cod.

- Handline catches of Cod occur exclusively inshore.

- Pot Catches of Snow Crab are the most spread out of all gear type and covers almost all of the Grand Banks, except for 3Na, 3Nc, 3Nf, 3Oc and 3Od. Pot catches of Lobster occur only inshore.

- Finally, Dredge vessels operate off the Southeastern edge of the Grand Banks in subdivisions 3Na, 3Nb and 3Nd capturing Clams, Cockles and Scallops

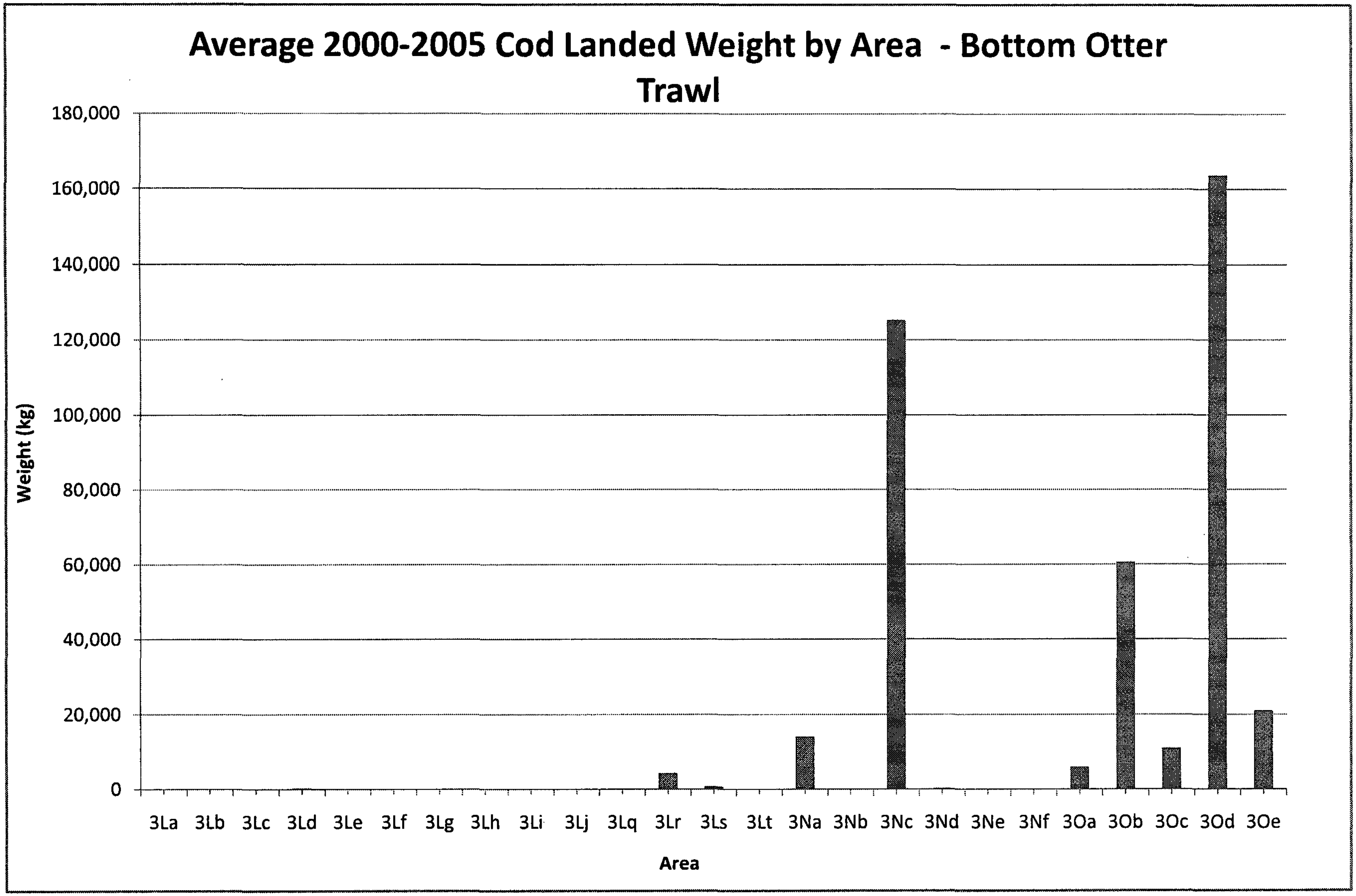

Figure A.9.1 Average Cod Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

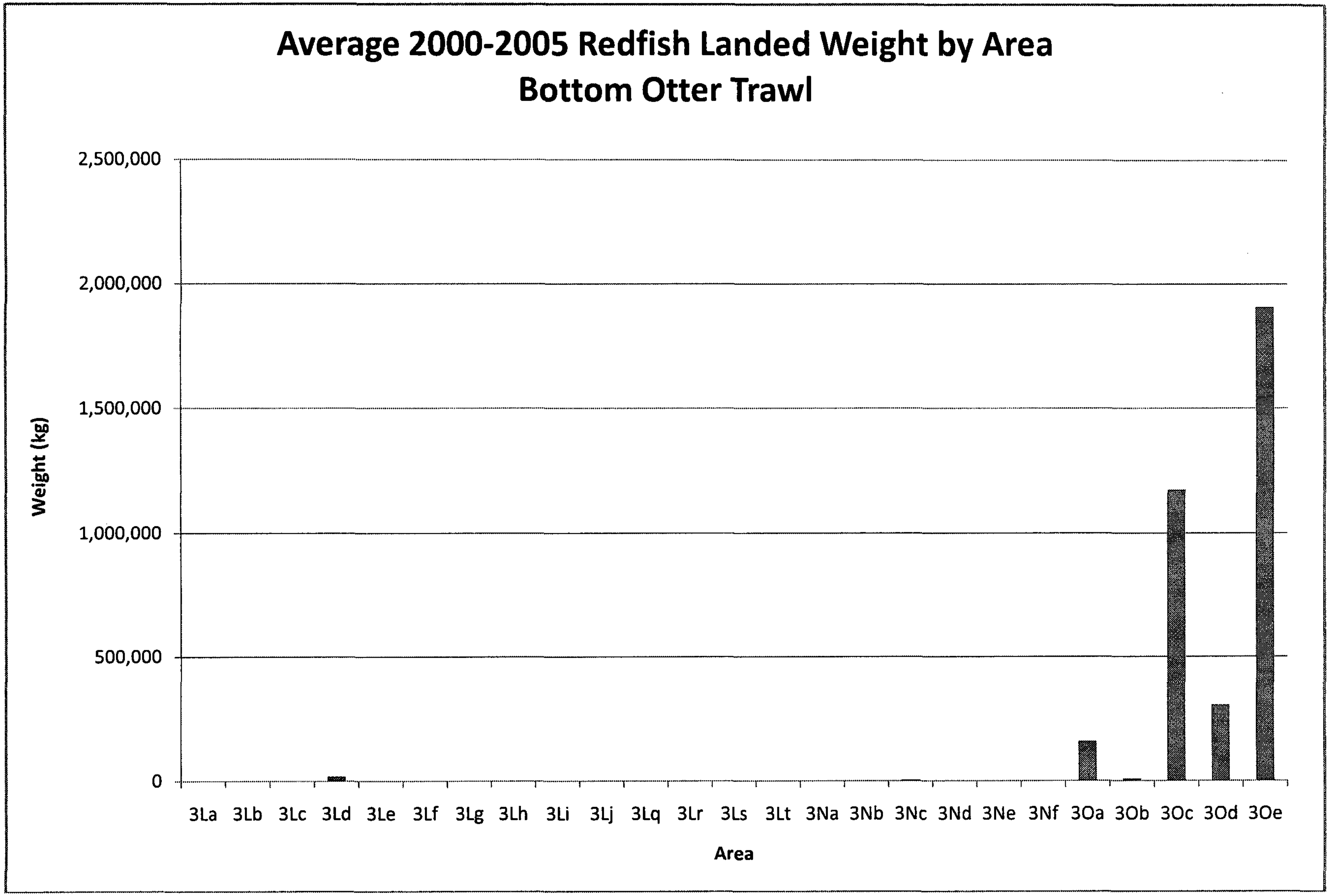

Figure A.9.2 Average Redfish Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

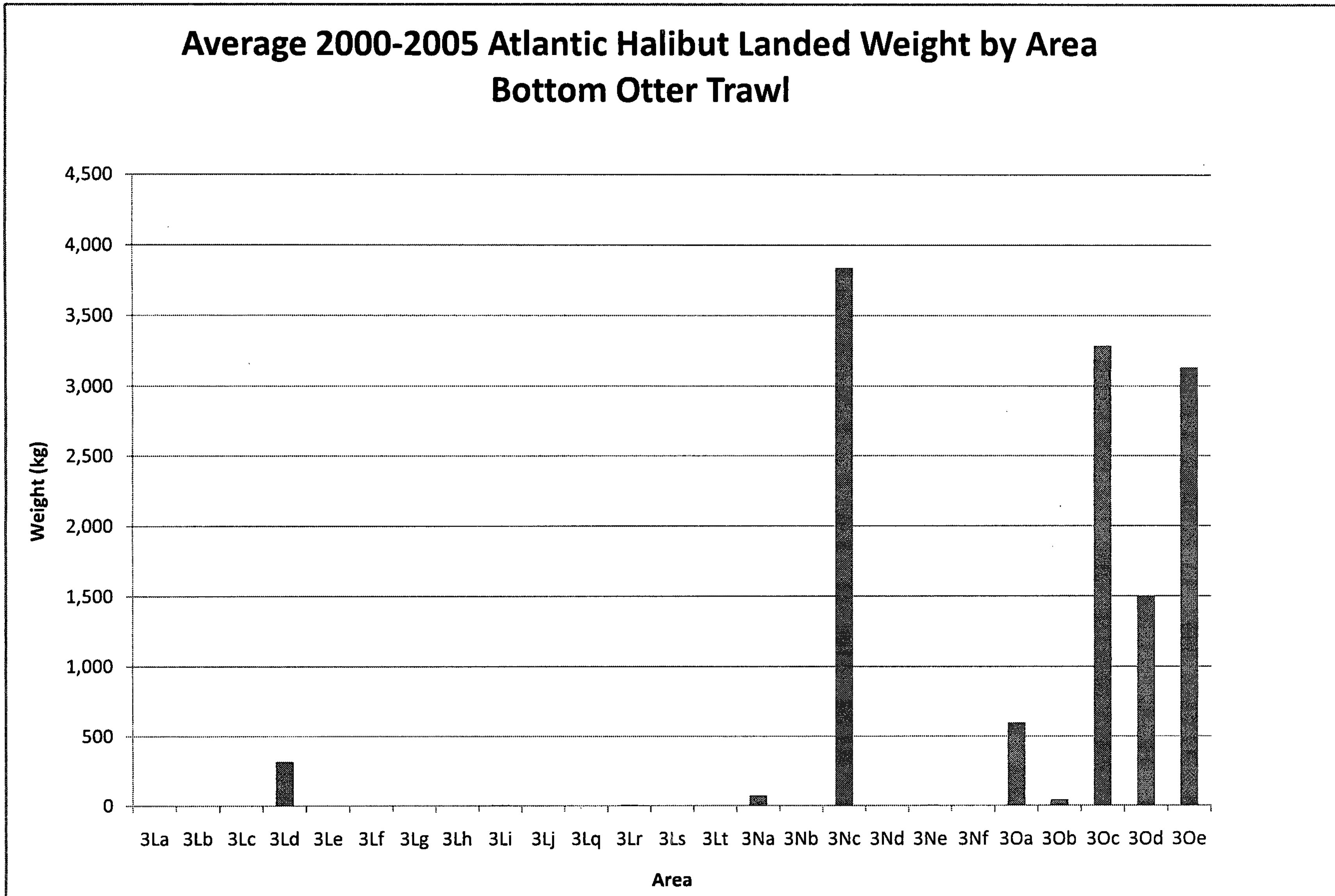

Figure A.9.3 Average Atlantic Halibut Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

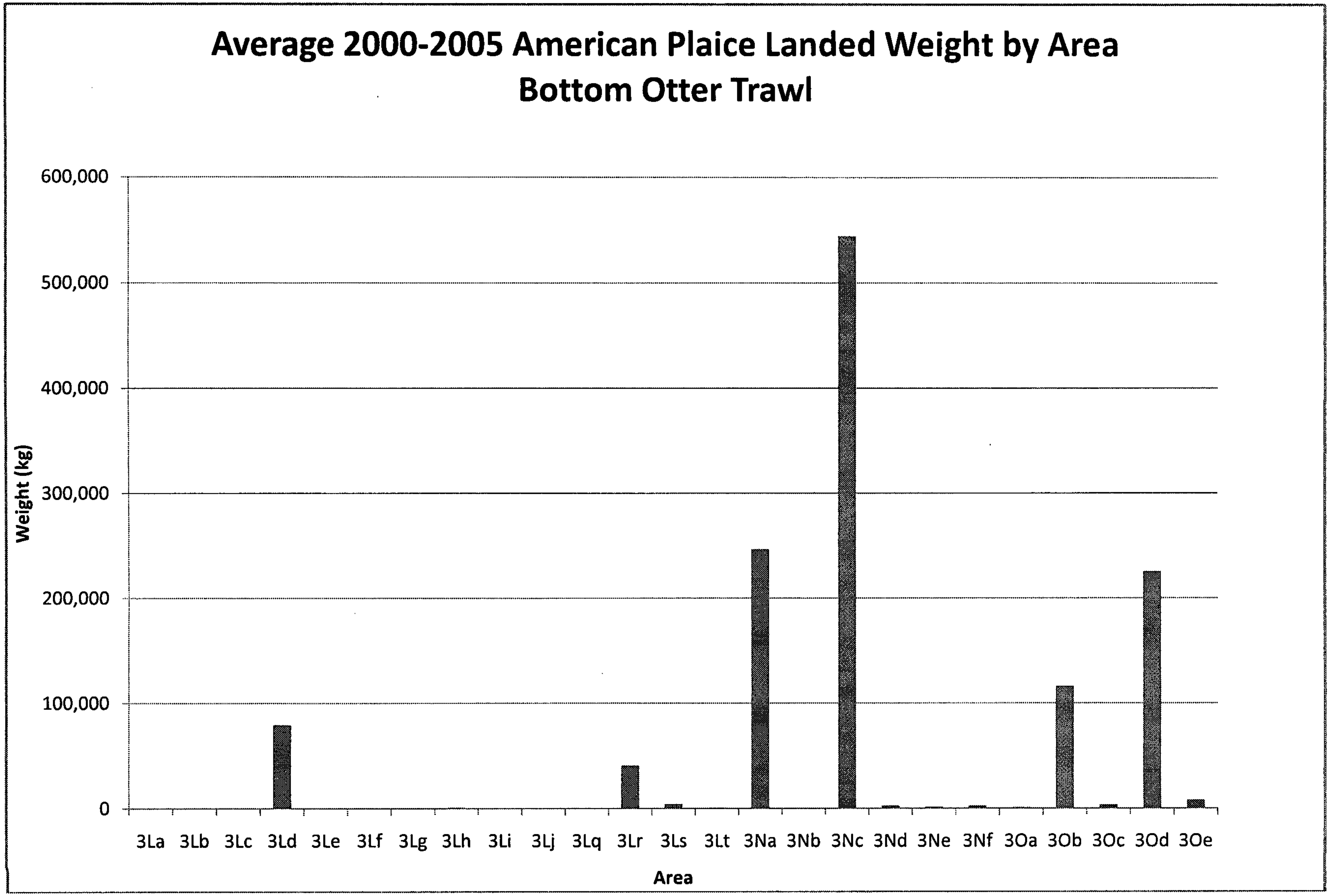

Figure A.9.4 Average American Plaice Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

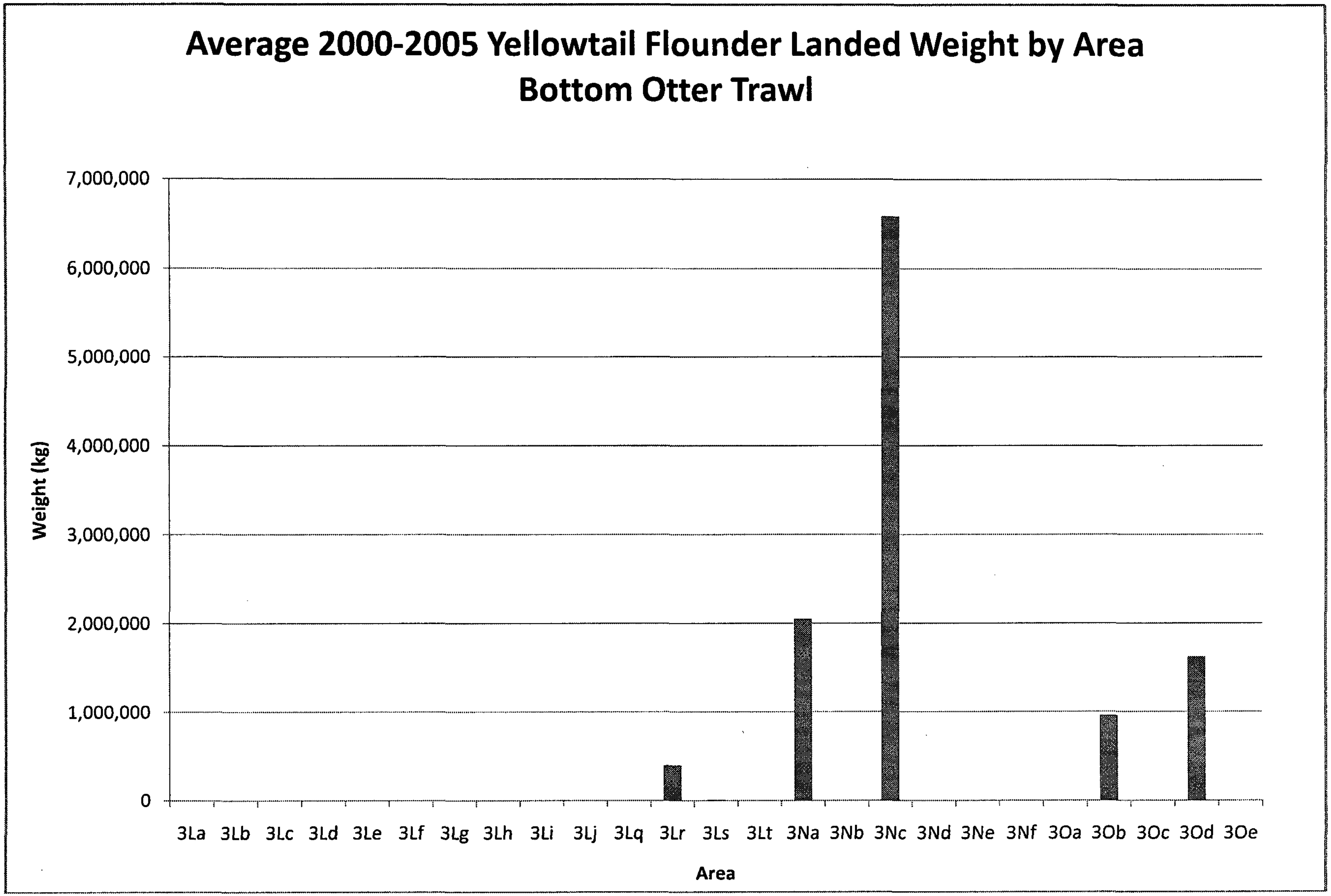

Figure A.9.5 Average Yellowtail Flounder Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

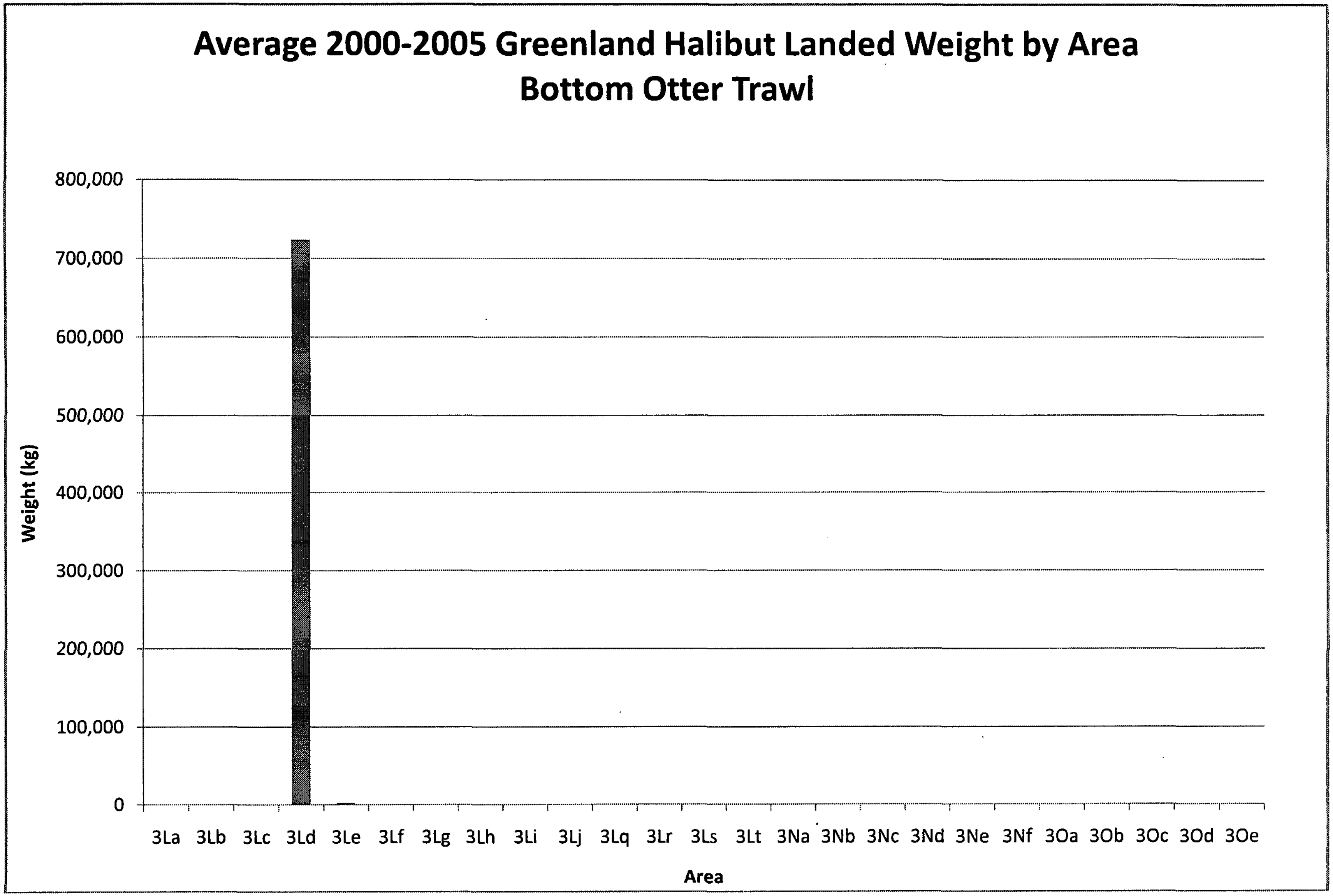

Figure A.9.6 Average Greenland Halibut Landed Weight by Area – Bottom Otter Trawl. Years 2000-2005.

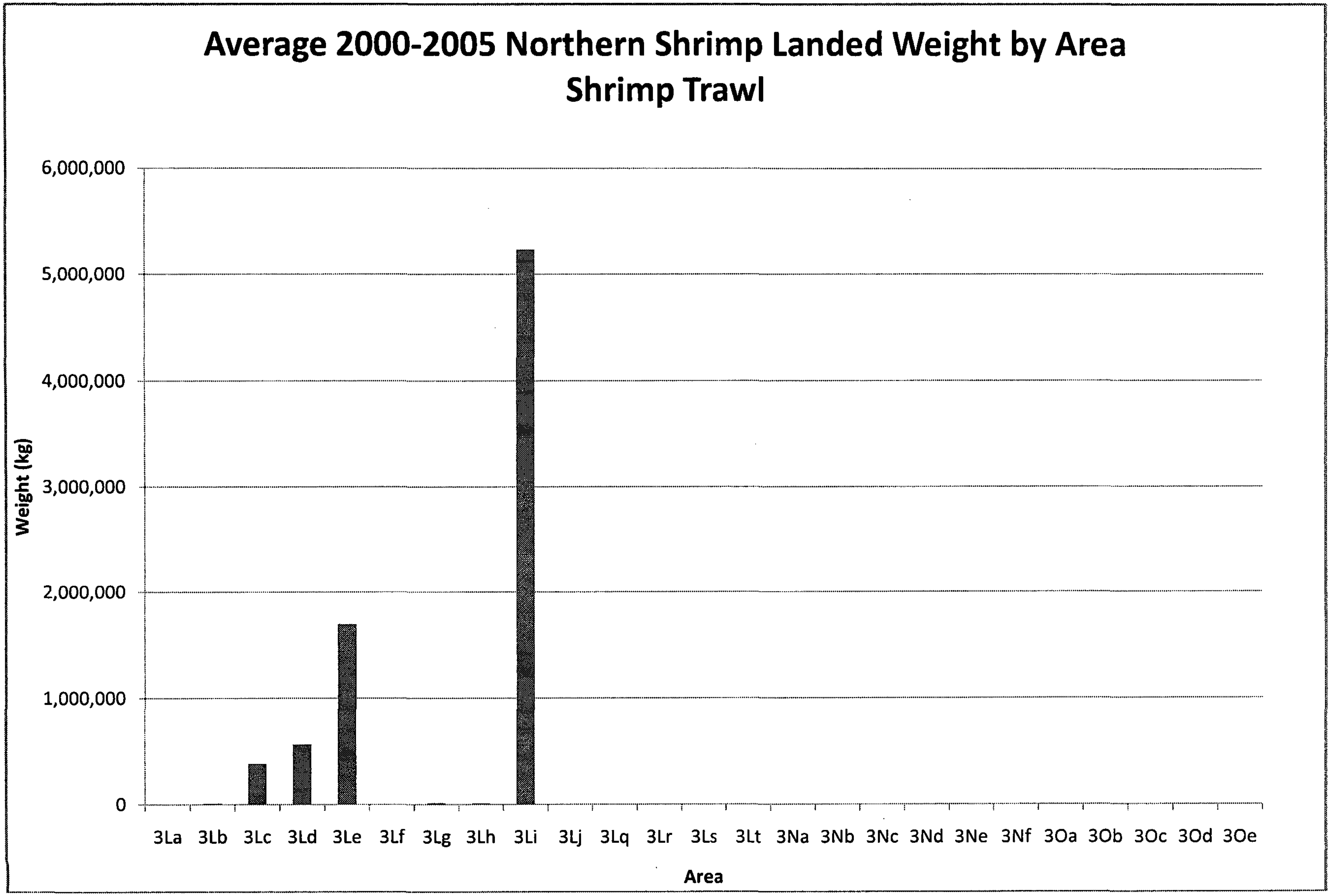

Figure A.9.7 Average Northern Shrimp Landed Weight by Area – Shrimp Trawl. Years 2000-2005.

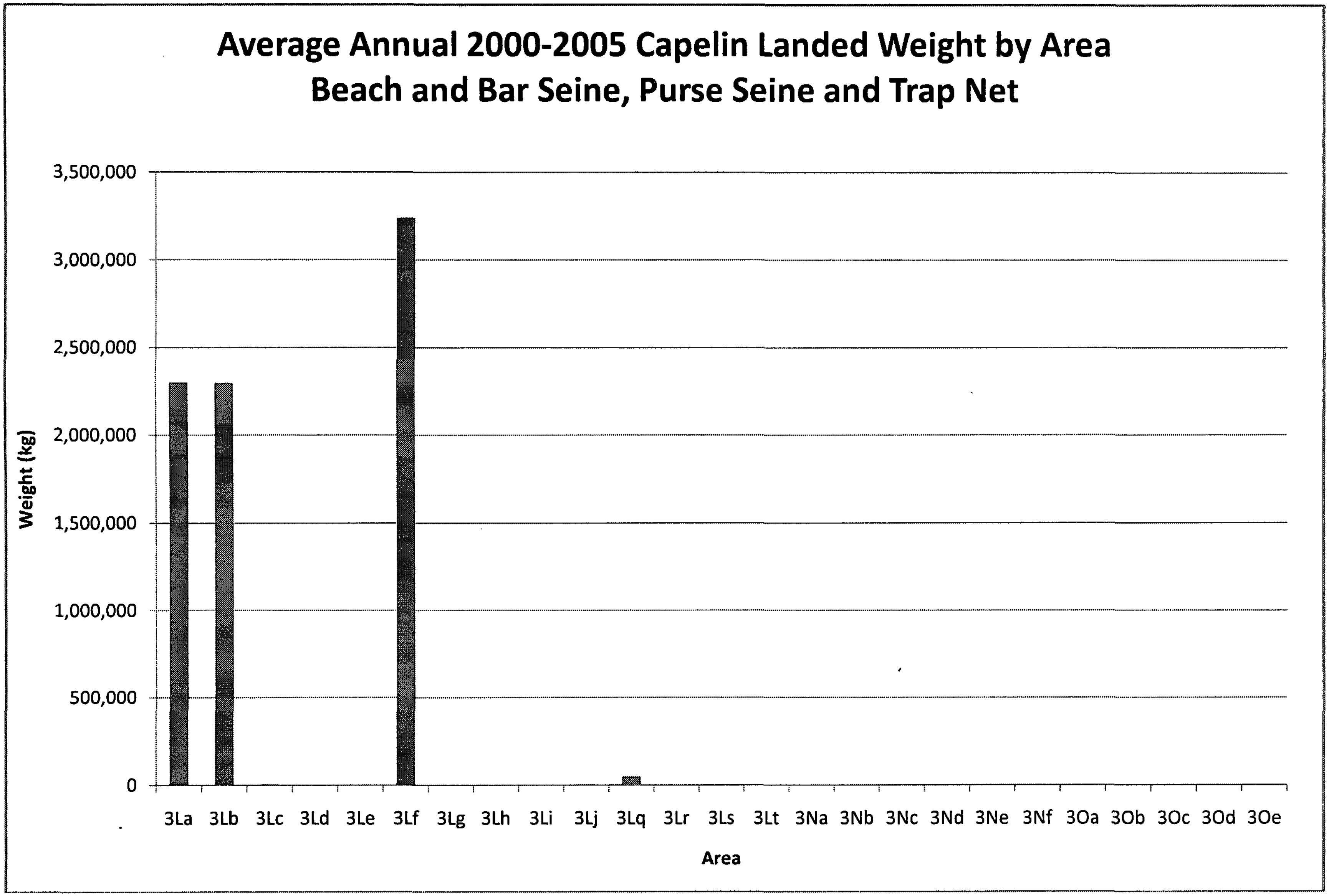

Figure A.9.8 Average Capelin Landed Weight by Area – Beach and Bar Seine, Purse Seine and Trap Net. Years 2000-2005.

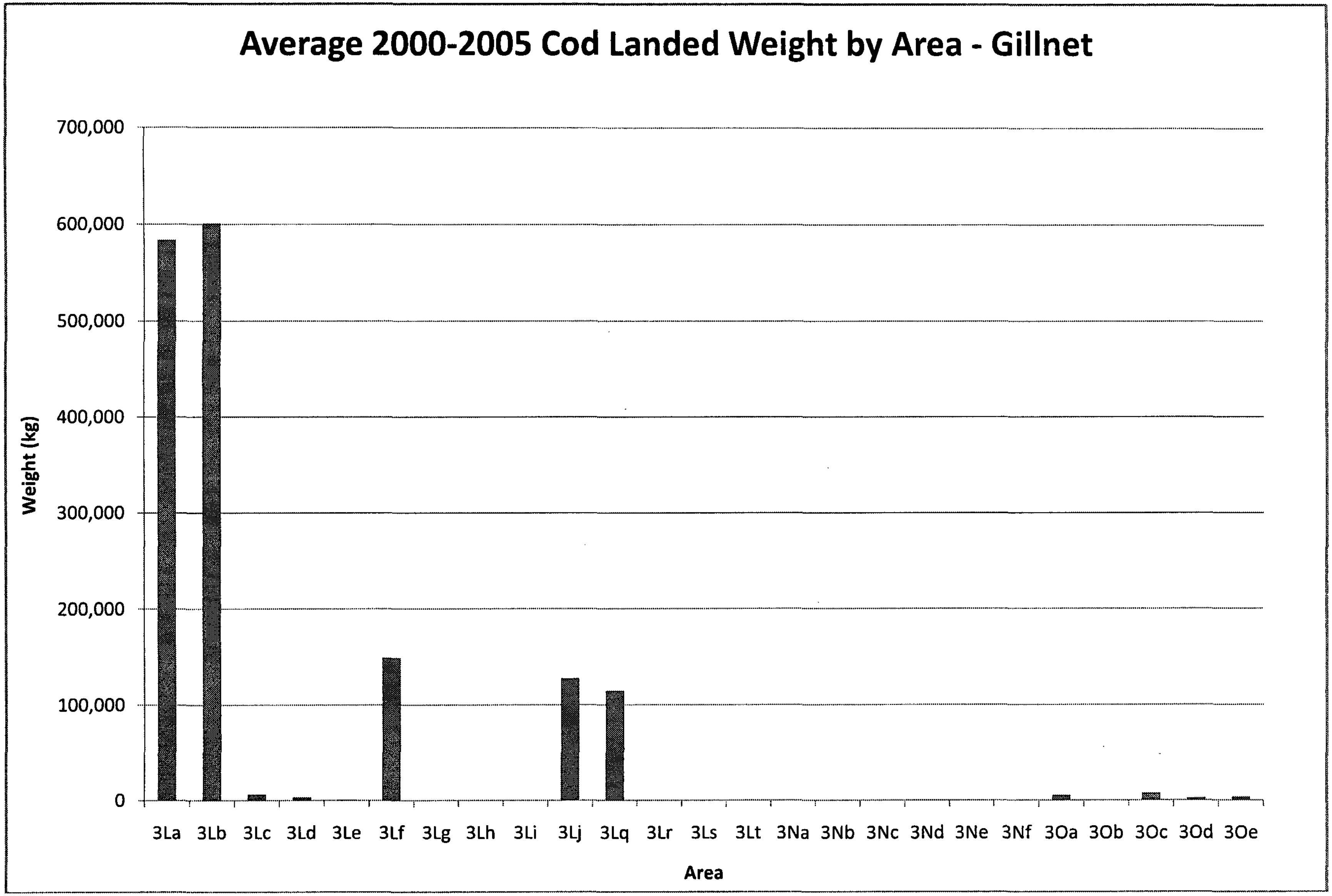

Figure A.9.9 Average Cod Landed Weight by Area – Gillnet. Years 2000-2005.

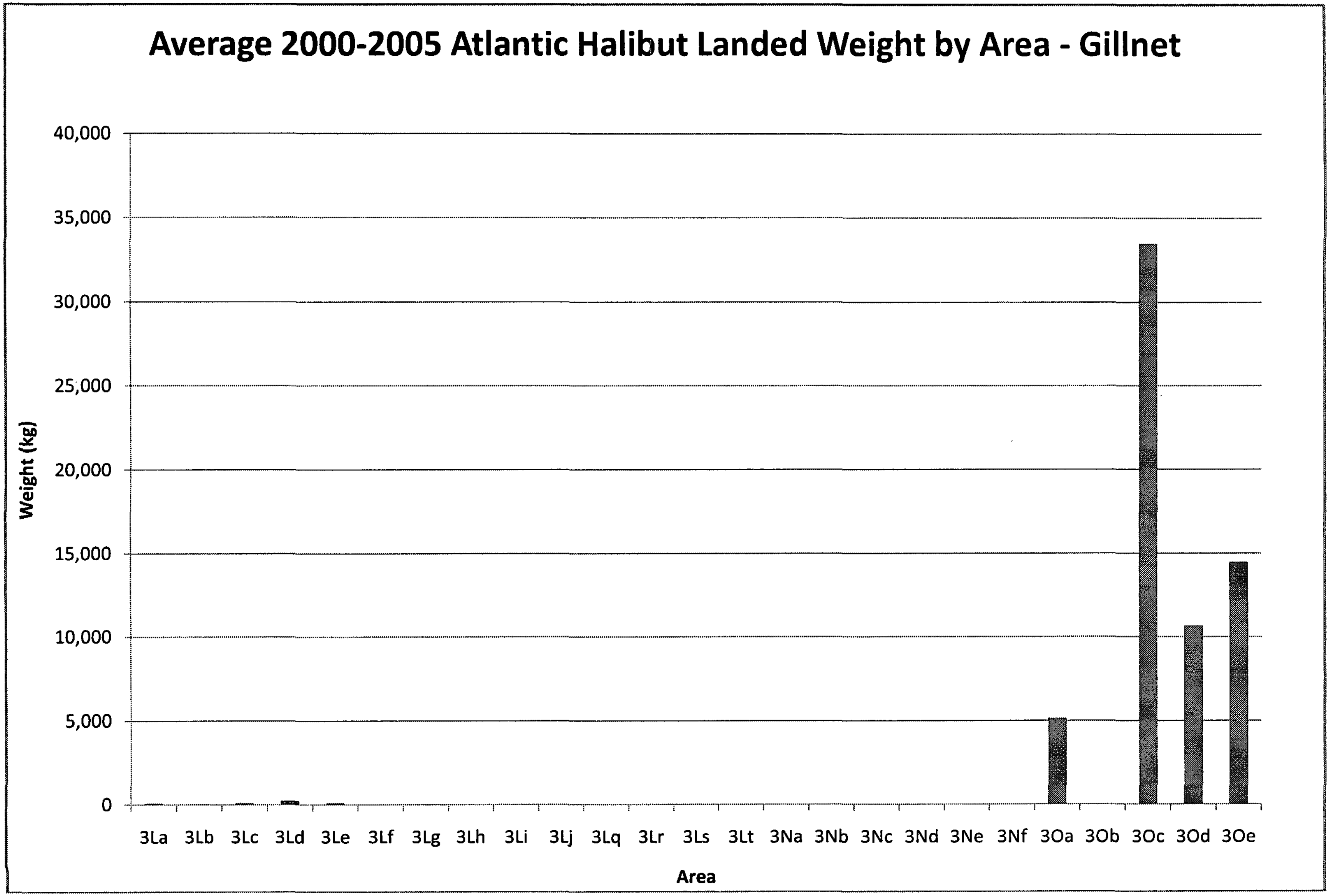

Figure A.9.10 Average Atlantic Halibut Landed Weight by Area – Gillnet. Years 2000-2005.

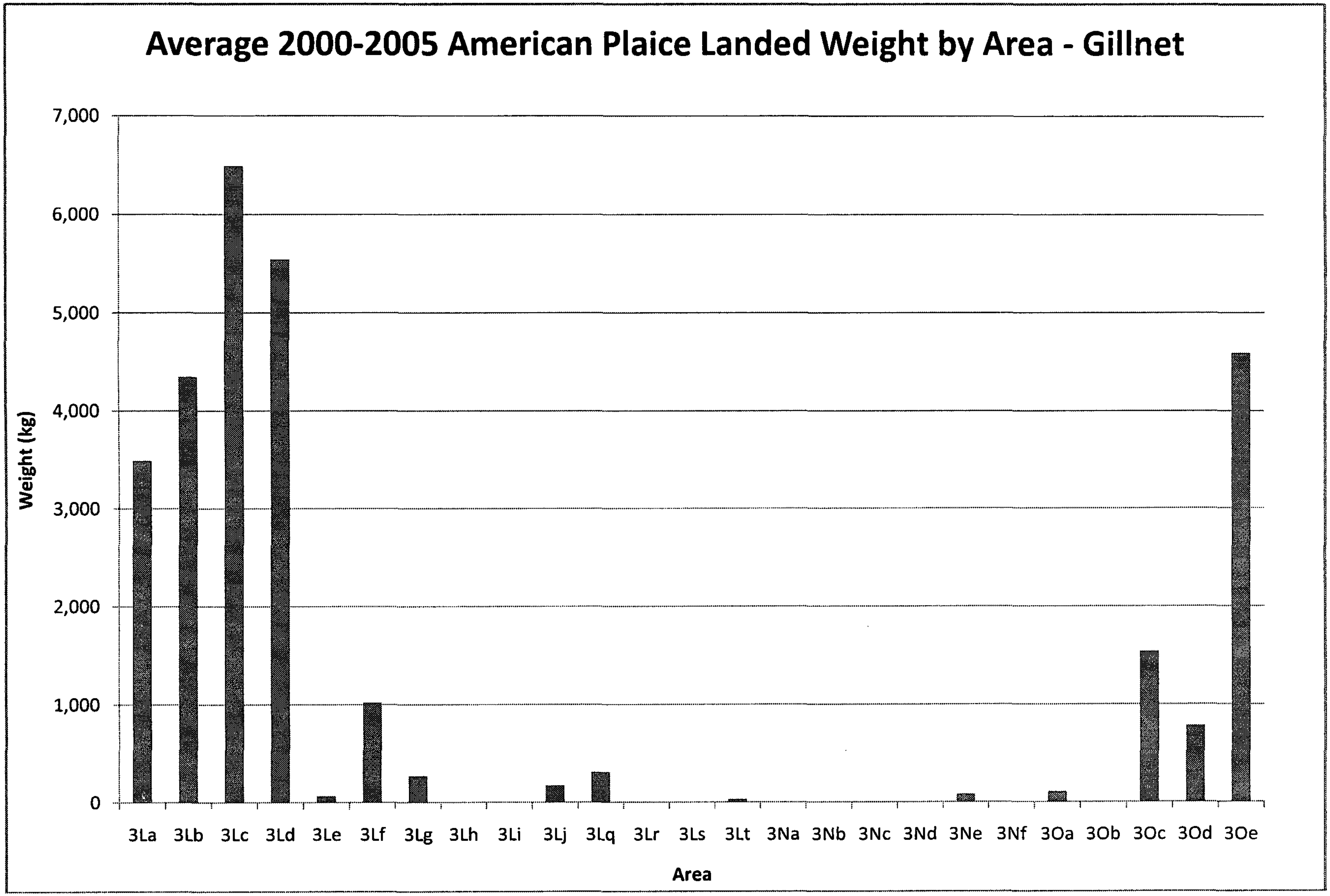

Figure A.9.11 Average American Plaice Landed Weight by Area – Gillnet. Years 2000-2005.

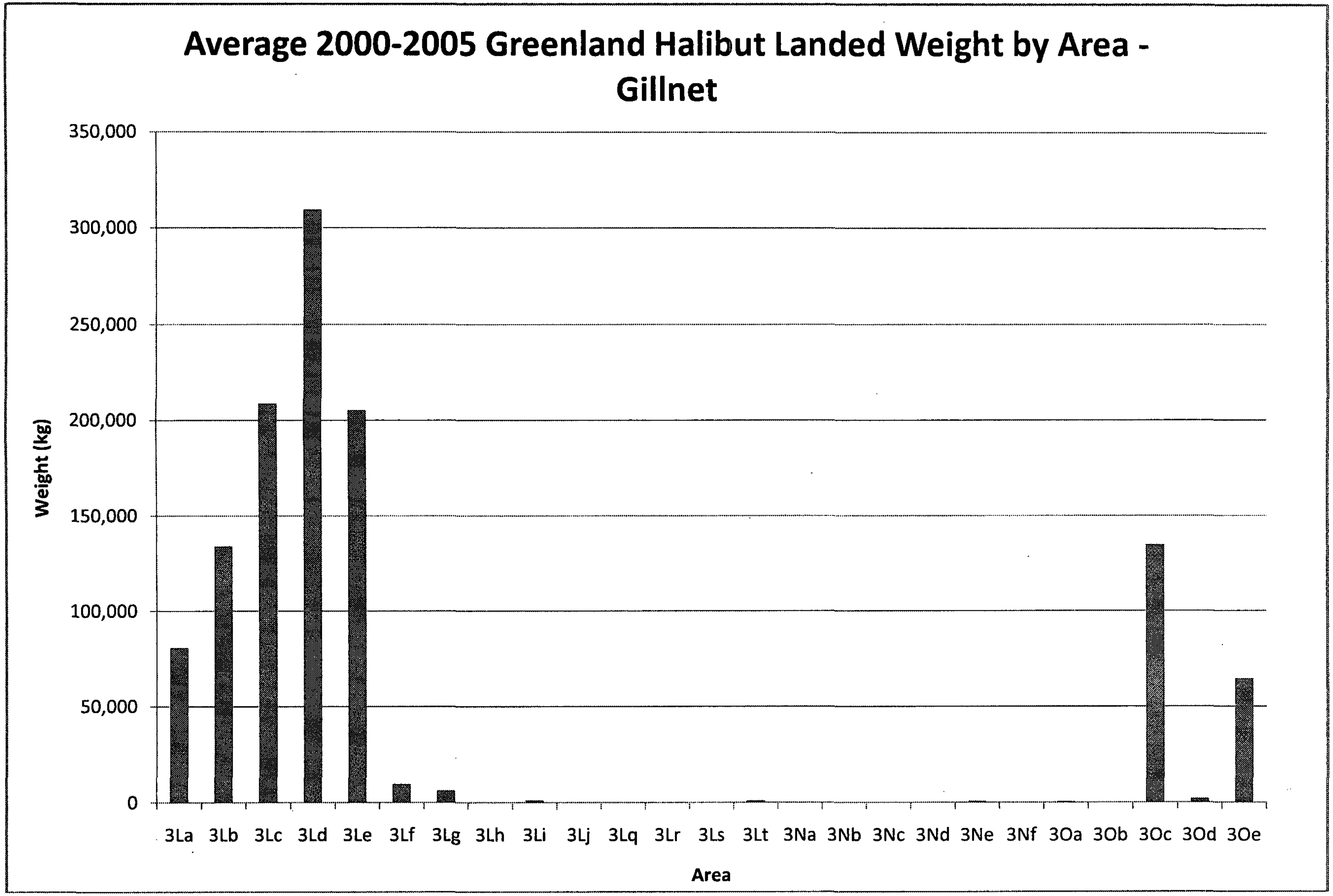

Figure A.9.12 Average Greenland Halibut Landed Weight by Area –Gillnet. Years 2000-2005.

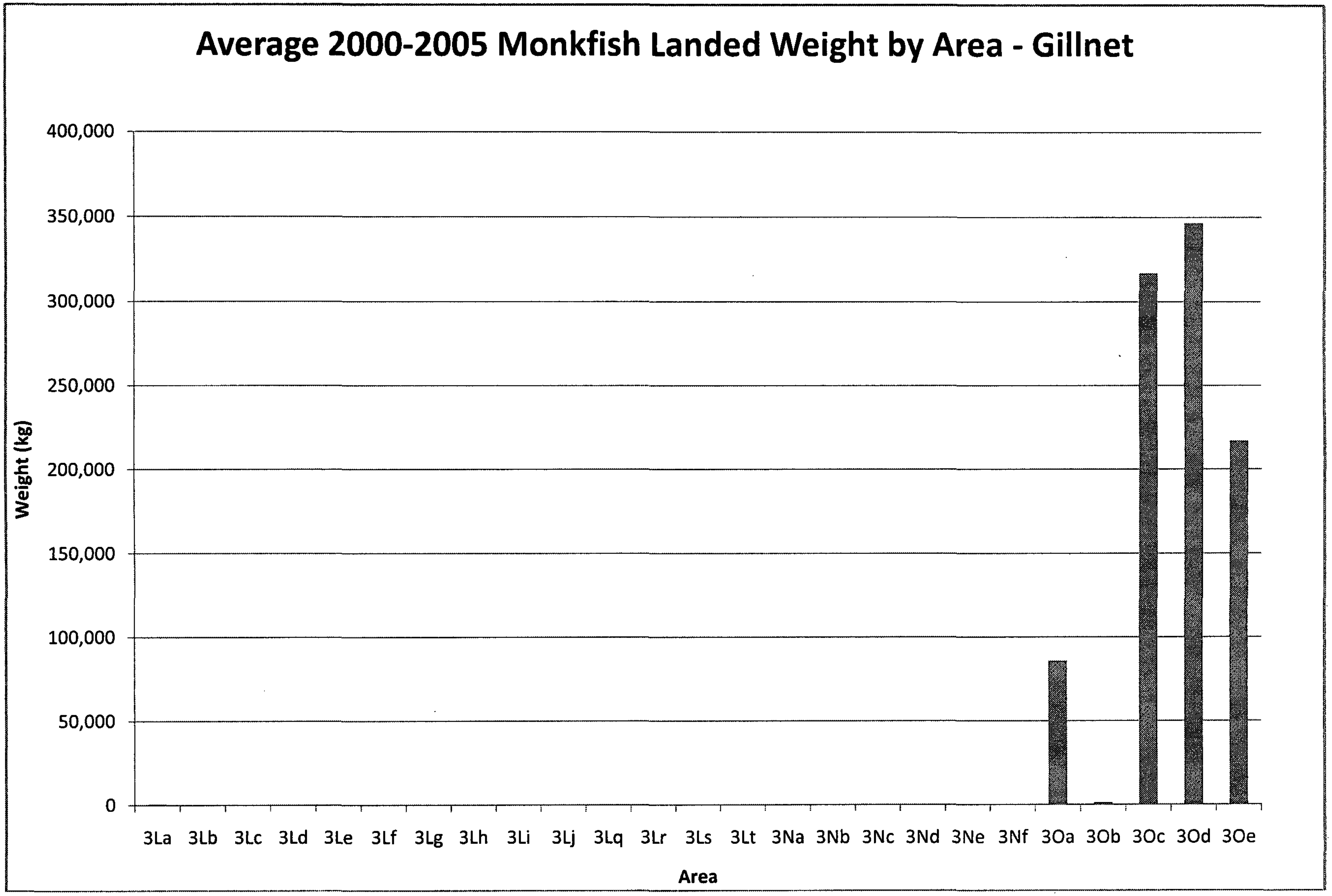

Figure A.9.13 Average Monkfish Landed Weight by Area – Gillnet. Years 2000-2005.

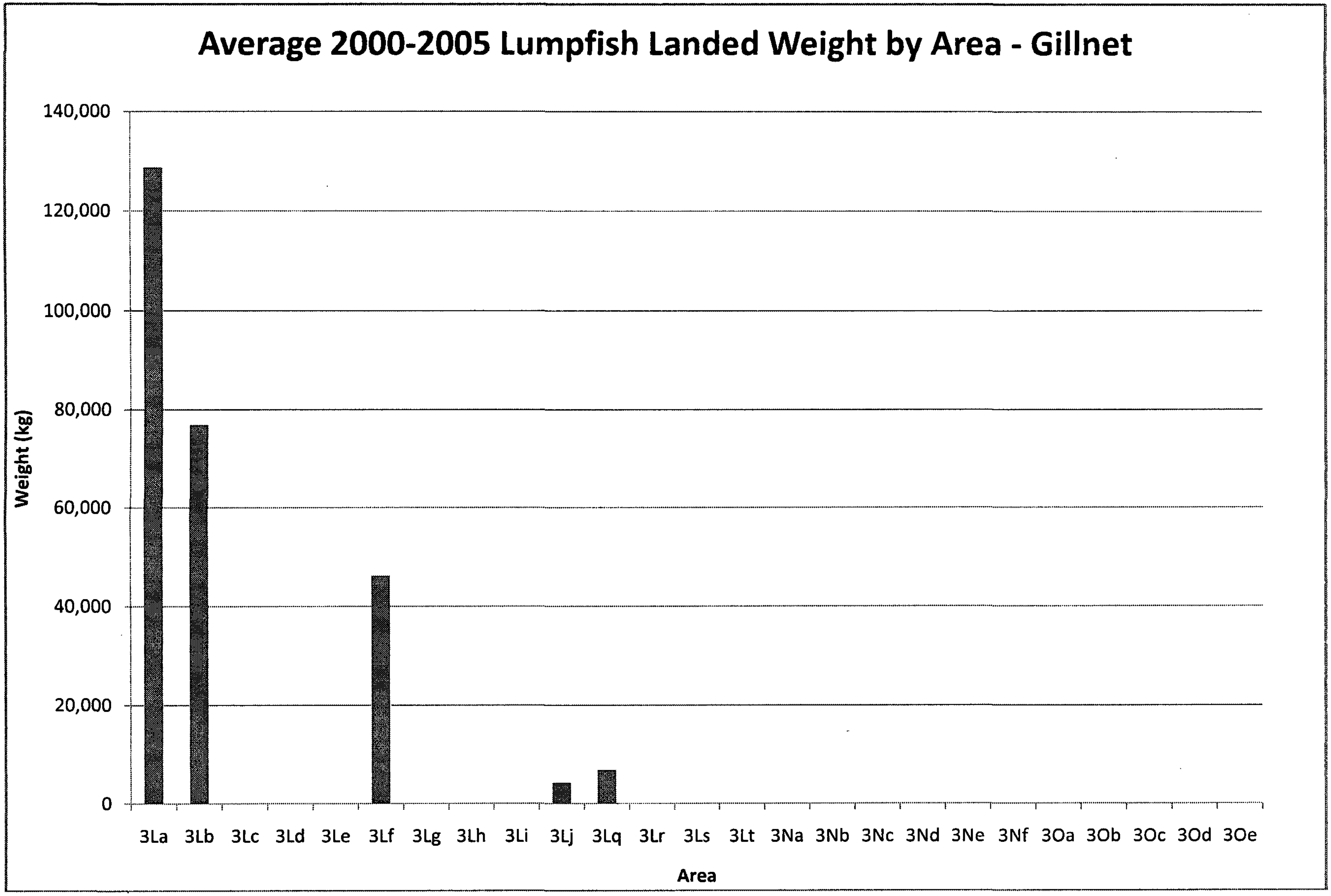

Figure A.9.14 Average Lumpfish Landed Weight by Area – Gillnet. Years 2000-2005.

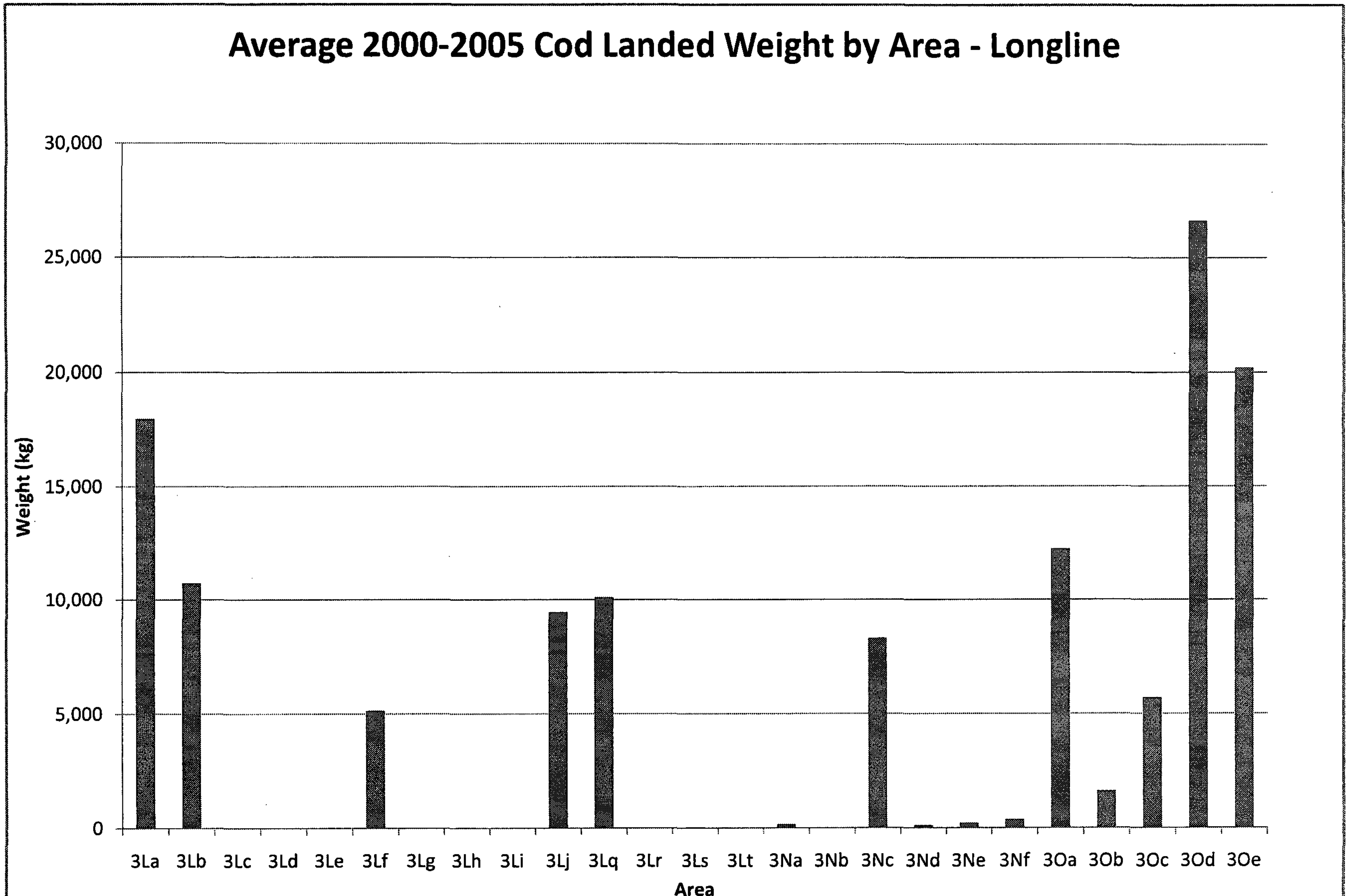

Figure A.9.15 Average Cod Landed Weight by Area – Longline. Years 2000-2005.

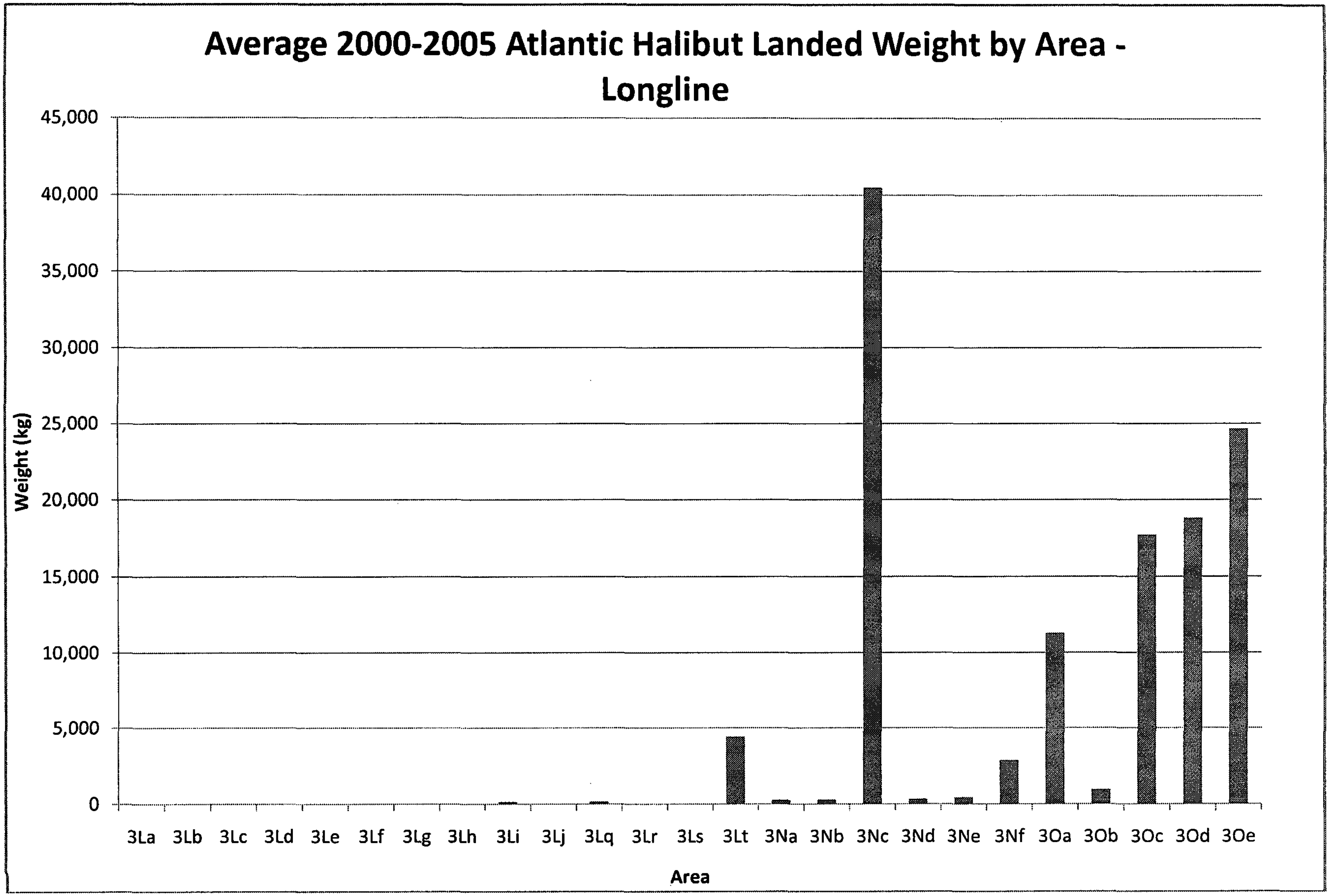

Figure A.9.16 Average Atlantic Halibut Landed Weight by Area –Longline. Years 2000-2005.

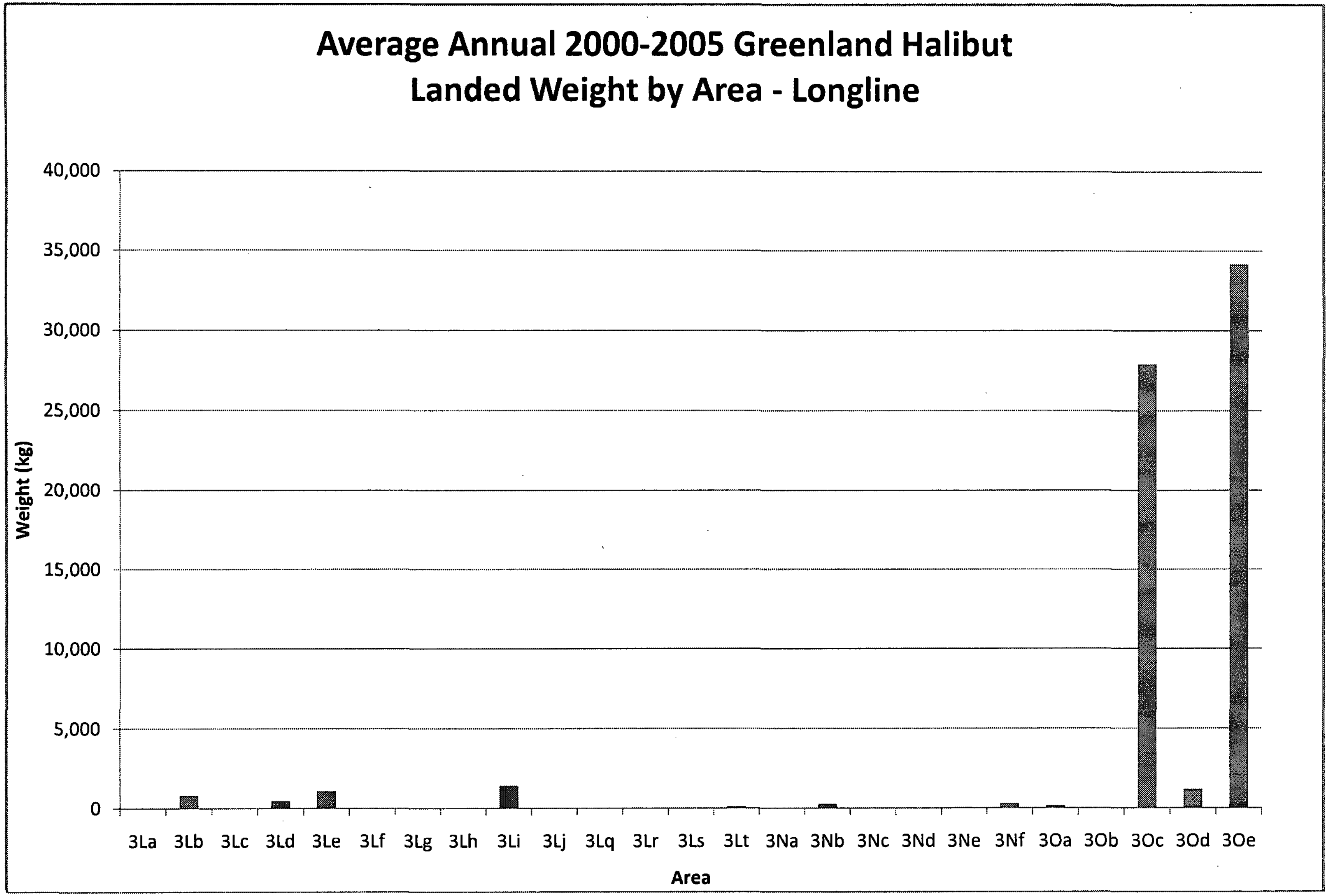

Figure A.9.17 Average Greenland Halibut Landed Weight by Area – Longline. Years 2000-2005.

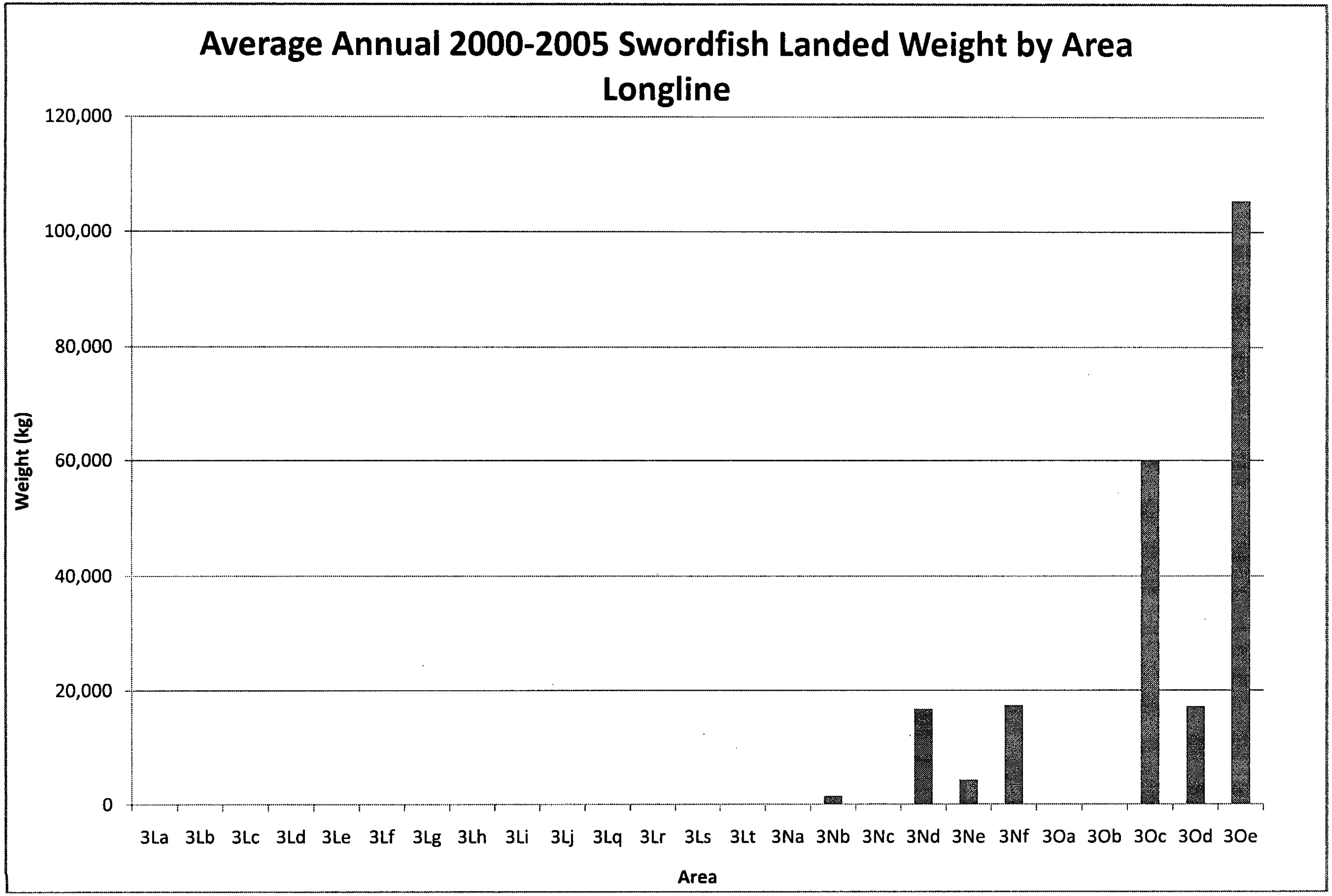

Figure A.9.18 Average Swordfish Landed Weight by Area – Longline. Years 2000-2005.

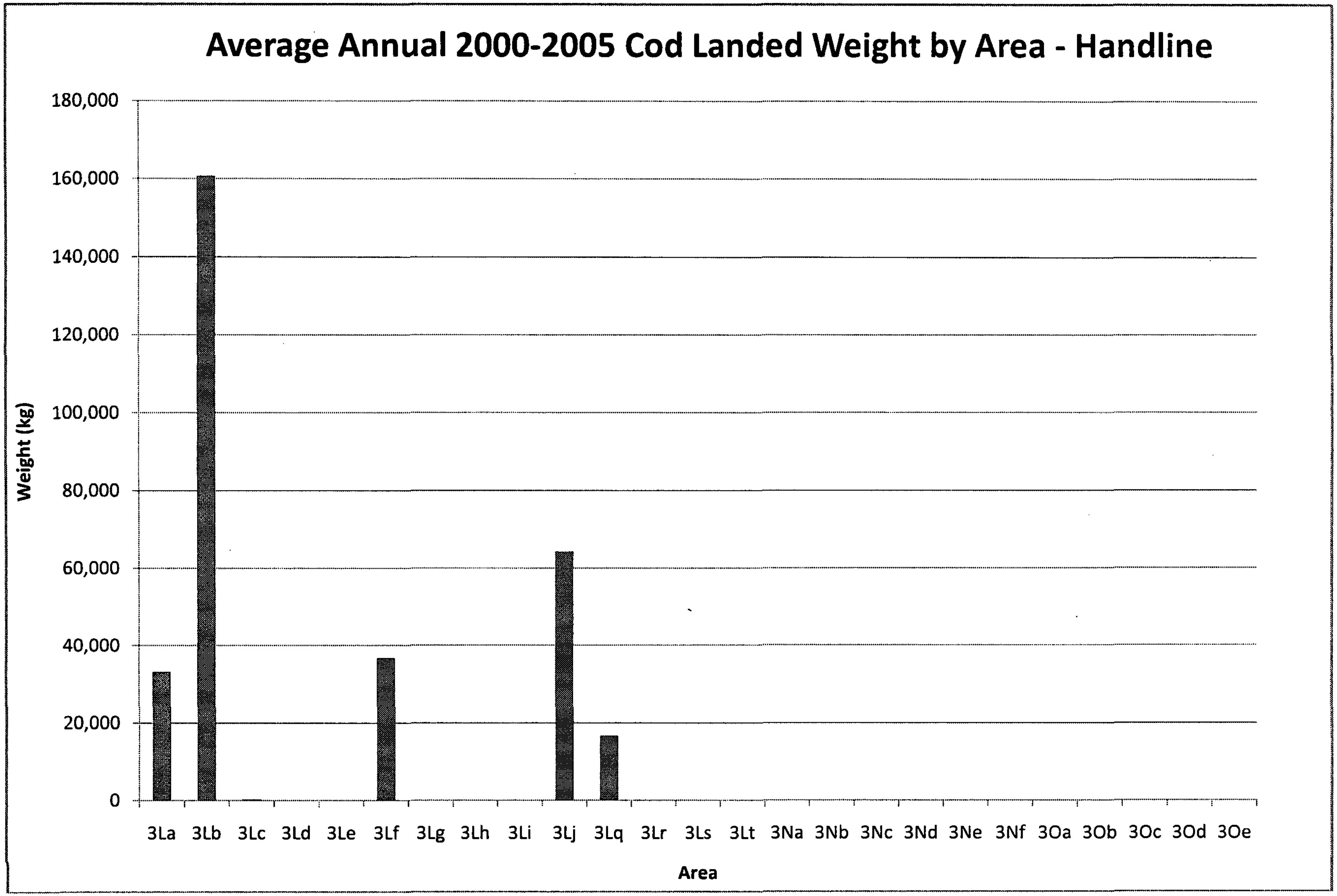

Figure A.9.19 Average Cod Landed Weight by Area – Handline. Years 2000-2005.

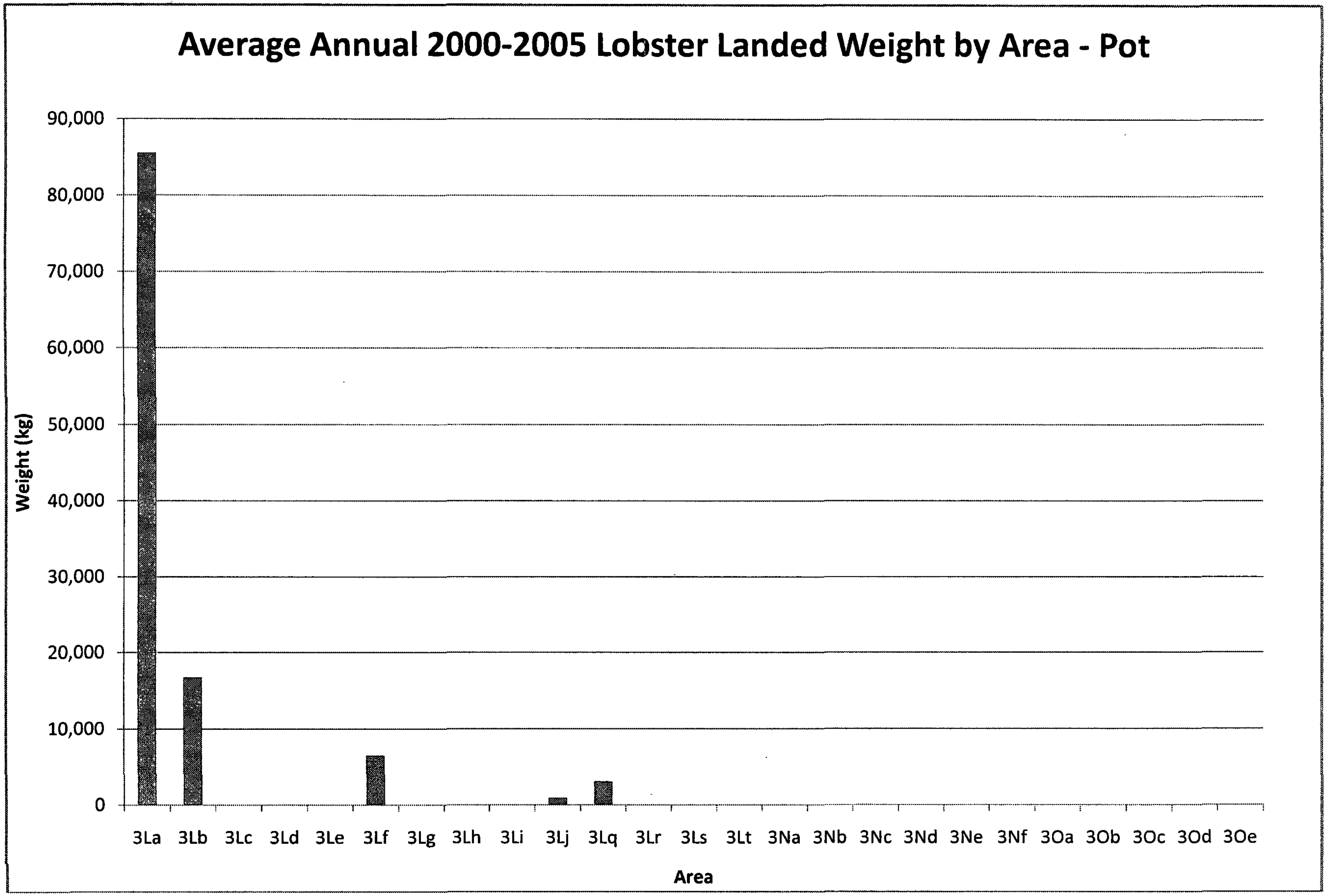

Figure A.9.20 Average Lobster Landed Weight by Area – Pot. Years 2000-2005.

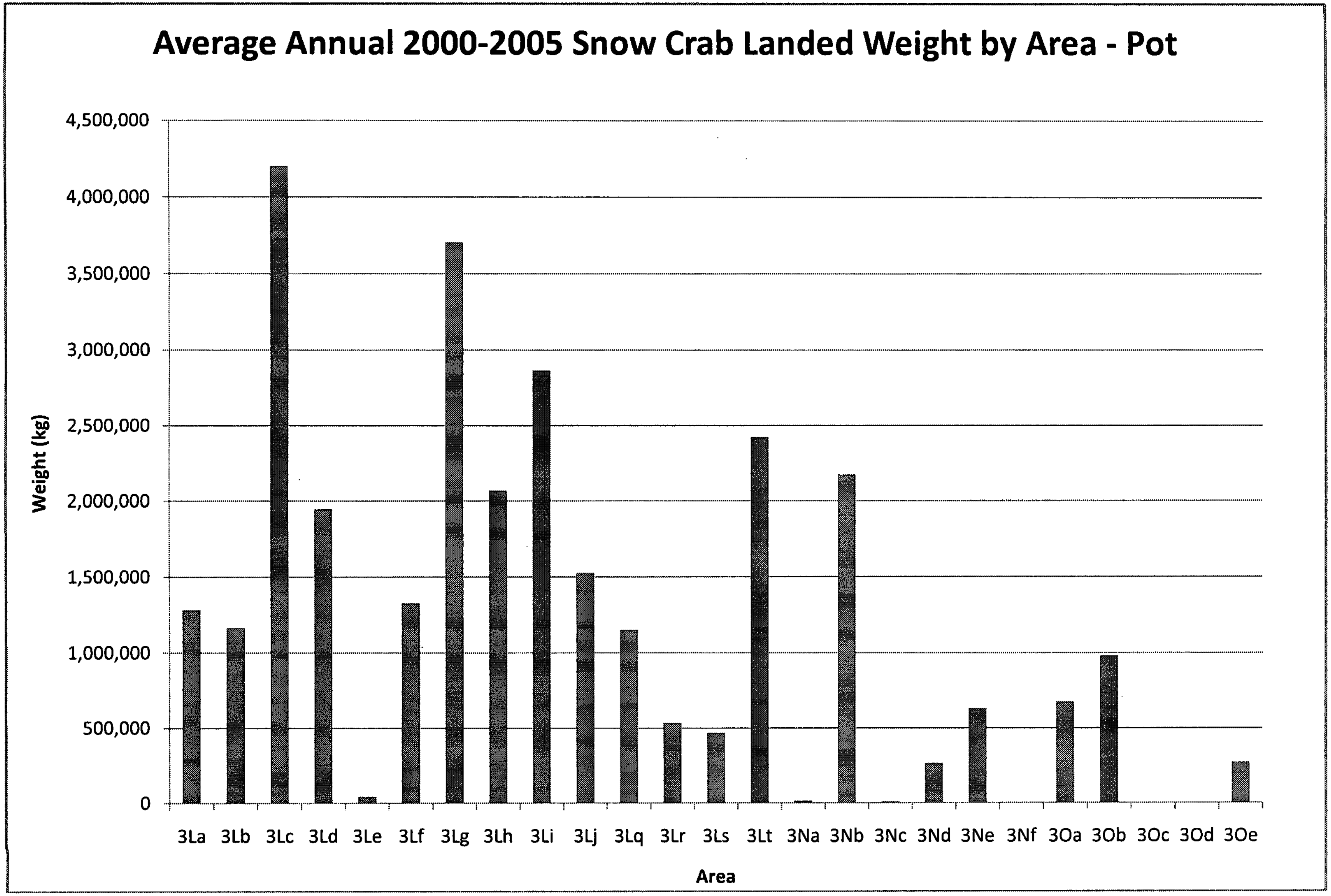

Figure A.9.21 Average Snow Crab Landed Weight by Area – Pot. Years 2000-2005.

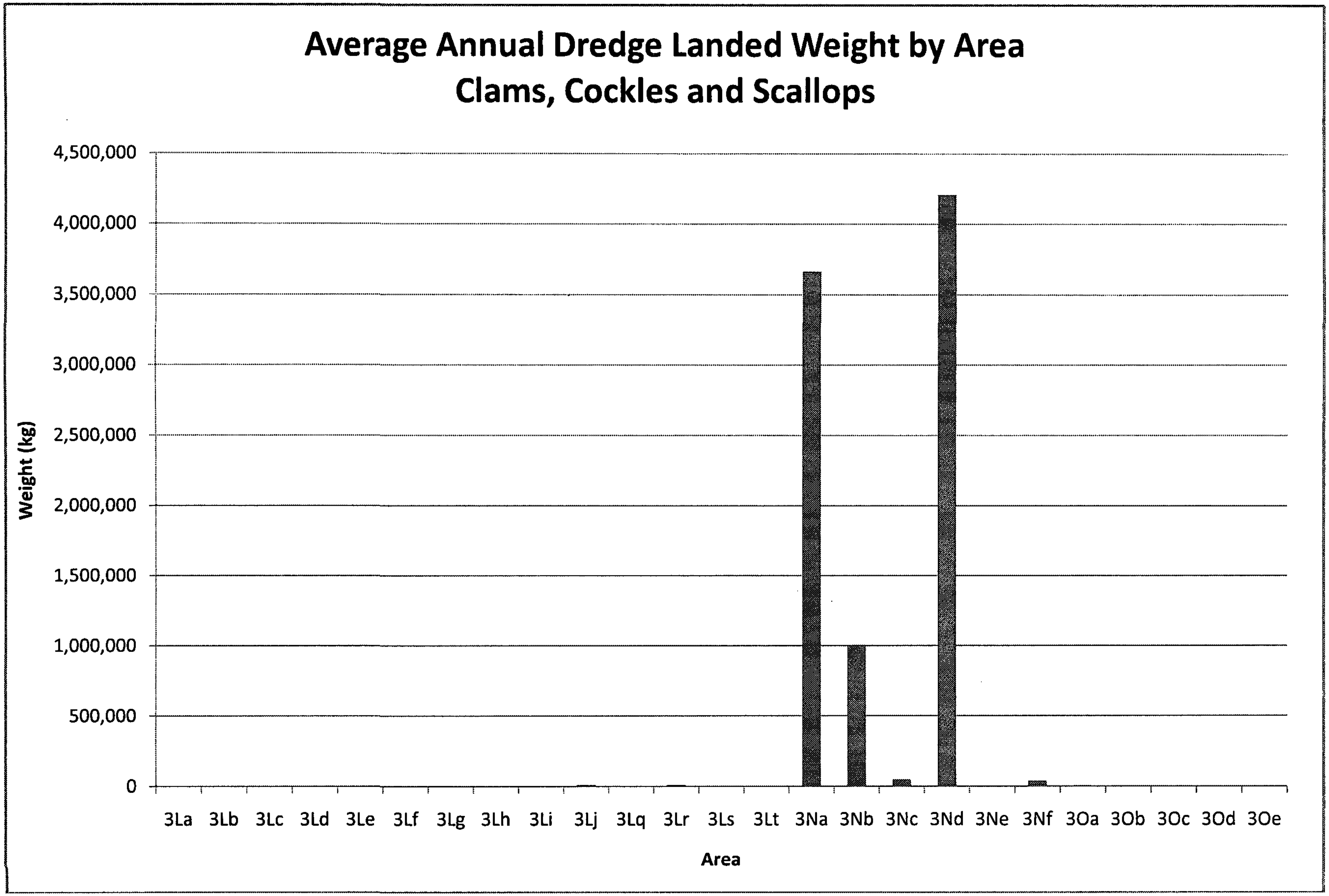

Figure A.9.22 Average Dredge Landed Weight by Area – Clams, Cockles and Scallops. Years 2000-2005.

A.9.1 Correlation Analysis

Most gear types operate in only three to five unit areas, except for Gillnet and Pot gears, both of which operate in inshore and offshore unit areas. Pot catches of Crab occur in all but five of the twenty-five subdivisions included in the study. However, a further step is needed before results of the analysis can be used in the model. This step will show that the average annual catch weights by area for each species and gear type combination are representative of annual values. Table A.9.2 to Table A.9.25 show the high level of correlation of the catch by area and support the use of average annual values to describe the spatial component of the Grand Banks catches for the years 2000 to 2005.

Table A.9.2 Correlation Analysis Year-to-year Bottom Otter Trawl catches by NAFO subdivisions 3La to 3Oe.

Bottom Otter Trawl	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.82	1.00				
2002	0.65	0.82	1.00			
2003	0.64	0.85	0.94	1.00		
2004	0.66	0.84	0.96	0.98	1.00	
2005	0.75	0.87	0.98	0.92	0.95	1.00

Table A.9.3 Correlation Analysis Year-to-year Shrimp Trawl catches by NAFO subdivisions 3La to 3Oe.

Shrimp Trawl	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	1.00	1.00				
2002	0.99	0.99	1.00			
2003	0.98	0.97	0.96	1.00		
2004	0.99	1.00	0.99	0.95	1.00	
2005	0.98	0.99	1.00	0.94	1.00	1.00

Table A.9.4 Correlation Analysis Year-to-year Beach and Bar Seine catches by NAFO subdivisions 3La to 3Oe.

Beach and Bar Seine	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.99	1.00				
2002	0.99	0.96	1.00			
2003	0.99	0.96	1.00	1.00		
2004	0.19	0.20	0.18	0.17	1.00	
2005	0.86	0.90	0.81	0.80	0.57	1.00

Table A.9.5 Correlation Analysis Year-to-year Purse Seine catches by NAFO subdivisions 3La to 3Oe.

Purse Seine	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.86	1.00				
2002	0.96	0.97	1.00			
2003	0.91	0.99	0.99	1.00		
2004	0.98	0.93	0.98	0.97	1.00	
2005	0.82	1.00	0.95	0.97	0.89	1.00

Table A.9.6 Correlation Analysis Year-to-year Gillnet catches by NAFO subdivisions 3La to 3Oe.

Gillnet	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.98	1.00				
2002	0.77	0.79	1.00			
2003	0.10	0.12	0.55	1.00		
2004	0.62	0.56	0.61	0.46	1.00	
2005	0.82	0.80	0.66	0.31	0.75	1.00

Table A.9.7 Correlation Analysis Year-to-year Longline catches by NAFO subdivisions 3La to 3Oe.

Longline	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.77	1.00				
2002	0.68	0.85	1.00			
2003	0.50	0.84	0.90	1.00		
2004	0.55	0.89	0.85	0.84	1.00	
2005	0.72	0.92	0.94	0.90	0.94	1.00

Table A.9.8 Correlation Analysis Year-to-year Handline catches by NAFO subdivisions 3La to 3Oe.

Handline	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.96	1.00				
2002	0.88	0.95	1.00			
2003	0.39	0.22	0.29	1.00		
2004	0.39	0.22	0.29	1.00	1.00	
2005	0.00	0.00	0.00	0.00	0.00	1.00

Table A.9.9 Correlation Analysis Year-to-year Trap Net catches by NAFO subdivisions 3La to 3Oe.

Trap Net	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.97	1.00				
2002	0.99	0.99	1.00			
2003	0.99	0.94	0.96	1.00		
2004	0.81	0.84	0.78	0.85	1.00	
2005	0.86	0.94	0.88	0.84	0.92	1.00

Table A.9.10 Correlation Analysis Year-to-year Pot catches by NAFO subdivisions 3La to 3Oe.

Pot	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.98	1.00				
2002	0.92	0.97	1.00			
2003	0.91	0.97	0.98	1.00		
2004	0.87	0.94	0.93	0.97	1.00	
2005	0.72	0.79	0.76	0.83	0.93	1.00

Table A.9.11 Correlation Analysis Year-to-year Dredge catches by NAFO subdivisions 3La to 3Oe.

Dredge	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.99	1.00				
2002	0.99	1.00	1.00			
2003	0.84	0.84	0.87	1.00		
2004	1.00	0.99	1.00	0.88	1.00	
2005	0.71	0.79	0.78	0.73	0.72	1.00

Table A.9.12 Correlation Analysis Year-to-year Cod catches by NAFO subdivisions 3La to 3Oe.

Cod	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.98	1.00				
2002	0.99	0.99	1.00			
2003	0.55	0.65	0.64	1.00		
2004	0.61	0.67	0.66	0.71	1.00	
2005	0.72	0.77	0.75	0.69	0.91	1.00

Table A.9.13 Correlation Analysis Year-to-year Redfish catches by NAFO subdivisions 3La to 3Oe.

Redfish	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.61	1.00				
2002	1.00	0.64	1.00			
2003	0.96	0.72	0.97	1.00		
2004	0.85	0.48	0.86	0.91	1.00	
2005	0.99	0.70	1.00	0.98	0.86	1.00

Table A.9.14 Correlation Analysis Year-to-year Atlantic Halibut catches by NAFO subdivisions 3La to 3Oe.

Atlantic Halibut	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.84	1.00				
2002	0.45	0.82	1.00			
2003	0.60	0.92	0.93	1.00		
2004	0.67	0.95	0.92	0.98	1.00	
2005	0.83	0.98	0.79	0.93	0.95	1.00

Table A.9.15 Correlation Analysis Year-to-year American Plaice catches by NAFO subdivisions 3La to 3Oe.

American Plaice	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.78	1.00				
2002	0.44	0.79	1.00			
2003	0.53	0.89	0.89	1.00		
2004	0.50	0.87	0.90	0.99	1.00	
2005	0.66	0.90	0.91	0.95	0.97	1.00

Table A.9.16 Correlation Analysis Year-to-year Yellowtail Flounder catches by NAFO subdivisions 3La to 3Oe.

Yellowtail Flounder	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.88	1.00				
2002	0.65	0.86	1.00			
2003	0.66	0.91	0.96	1.00		
2004	0.70	0.91	0.99	0.98	1.00	
2005	0.75	0.91	0.99	0.95	0.99	1.00

Table A.9.17 Correlation Analysis Year-to-year Greenland Halibut catches by NAFO subdivisions 3La to 3Oe.

Greenland Halibut	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.97	1.00				
2002	0.92	0.97	1.00			
2003	0.90	0.95	0.96	1.00		
2004	0.96	0.99	0.97	0.96	1.00	
2005	0.75	0.72	0.58	0.55	0.70	1.00

Table A.9.18 Correlation Analysis Year-to-year Monkfish catches by NAFO subdivisions 3La to 3Oe.

Monkfish	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.79	1.00				
2002	0.14	0.70	1.00			
2003	0.07	0.64	0.88	1.00		
2004	-0.01	0.27	0.42	0.60	1.00	
2005	0.03	0.46	0.64	0.85	0.92	1.00

Table A.9.19 Correlation Analysis Year-to-year Lumpfish catches by NAFO subdivisions 3La to 3Oe.

Lumpfish	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.96	1.00				
2002	1.00	0.95	1.00			
2003	1.00	0.98	0.99	1.00		
2004	0.94	0.99	0.92	0.97	1.00	
2005	0.97	0.99	0.95	0.98	0.99	1.00

Table A.9.20 Correlation Analysis Year-to-year Swordfish catches by NAFO subdivisions 3La to 3Oe.

Swordfish	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.92	1.00				
2002	0.98	0.88	1.00			
2003	0.63	0.56	0.64	1.00		
2004	0.48	0.46	0.46	0.97	1.00	
2005	0.84	0.78	0.84	0.90	0.83	1.00

Table A.9.21 Correlation Analysis Year-to-year Capelin catches by NAFO subdivisions 3La to 3Oe.

Capelin	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.90	1.00				
2002	0.95	0.99	1.00			
2003	0.97	0.96	0.99	1.00		
2004	0.87	0.99	0.98	0.95	1.00	
2005	0.81	0.96	0.94	0.92	0.99	1.00

Table A.9.22 Correlation Analysis Year-to-year Clams, Cockles and Scallops catches by NAFO subdivisions 3La to 3Oe.

Clams, Cockles and Scallops	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.99	1.00				
2002	0.99	1.00	1.00			
2003	0.84	0.84	0.87	1.00		
2004	1.00	0.99	1.00	0.88	1.00	
2005	0.71	0.79	0.78	0.73	0.72	1.00

Table A.9.23 Correlation Analysis Year-to-year Lobster catches by NAFO subdivisions 3La to 3Oe.

Lobster	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	1.00	1.00				
2002	1.00	1.00	1.00			
2003	1.00	1.00	1.00	1.00		
2004	1.00	1.00	1.00	1.00	1.00	
2005	1.00	1.00	1.00	1.00	1.00	1.00

Table A.9.24 Correlation Analysis Year-to-year Northern Shrimp catches by NAFO subdivisions 3La to 3Oe.

Northern Shrimp	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	1.00	1.00				
2002	0.99	0.99	1.00			
2003	0.98	0.97	0.96	1.00		
2004	0.99	1.00	0.99	0.95	1.00	
2005	0.98	0.99	1.00	0.94	1.00	1.00

Table A.9.25 Correlation Analysis Year-to-year Snow Crab catches by NAFO subdivisions 3La to 3Oe.

Snow Crab	2000	2001	2002	2003	2004	2005
2000	1.00					
2001	0.98	1.00				
2002	0.92	0.97	1.00			
2003	0.91	0.97	0.98	1.00		
2004	0.87	0.94	0.93	0.97	1.00	
2005	0.72	0.79	0.76	0.83	0.93	1.00

A.10 Significant Species and Gear Type Combinations – Weekly Catches

The seasonal component of harvesting activity by gear type was shown in section A.5. Seasonal activity can now be identified for each significant species and gear type combination using average weekly landed weight for the years 2000 to 2005.

- Bottom Otter Trawl catches generally exhibit a pattern of two seasons where most activity occurs; from week 12 to 22 and 35 to 48, except in the case of Redfish and Atlantic Halibut that show a similar level of activity between those two seasons. Greenland Halibut is the exception because it is captured mainly from week 11 to week 32. This is consistent with our spatial analysis that demonstrated Greenland Halibut catches occurred in a different location from the other species. The main season of shrimp trawl catches begins on week 21 and ends on week 30 with a peak on week 24. A lower peak occurs on weeks 37 and 38 and a third at the beginning of the year through to week 5.

- The harvest of Capelin by Beach and Bar Seine, Purse Seine and Trap Net take place from week 26 to 30. Gillnet activity shows between one and two seasons of catches depending on the species. Regardless of the species, we see a clear trend of small catches at the beginning of the season gradually increasing until a peak is reached, then decreasing again gradually.

- The seasons of gillnet catches vary depending on the species. Longline catches are more spread out through the year, with several peaks of high catches, except for

Swordfish that shows one main season of catches. Hand line catches of Cod exhibit one four-week season of high catches from week 13 to week 16, and a second, longer season of lower catches later in the year.

- Pot catches of Lobster and Snow Crab show one season of activity from week 18 to 27 for Lobster and a slightly longer season for Snow Crab.

- Finally, Dredge catches of Clams, Cockles and Scallops occur throughout the year.

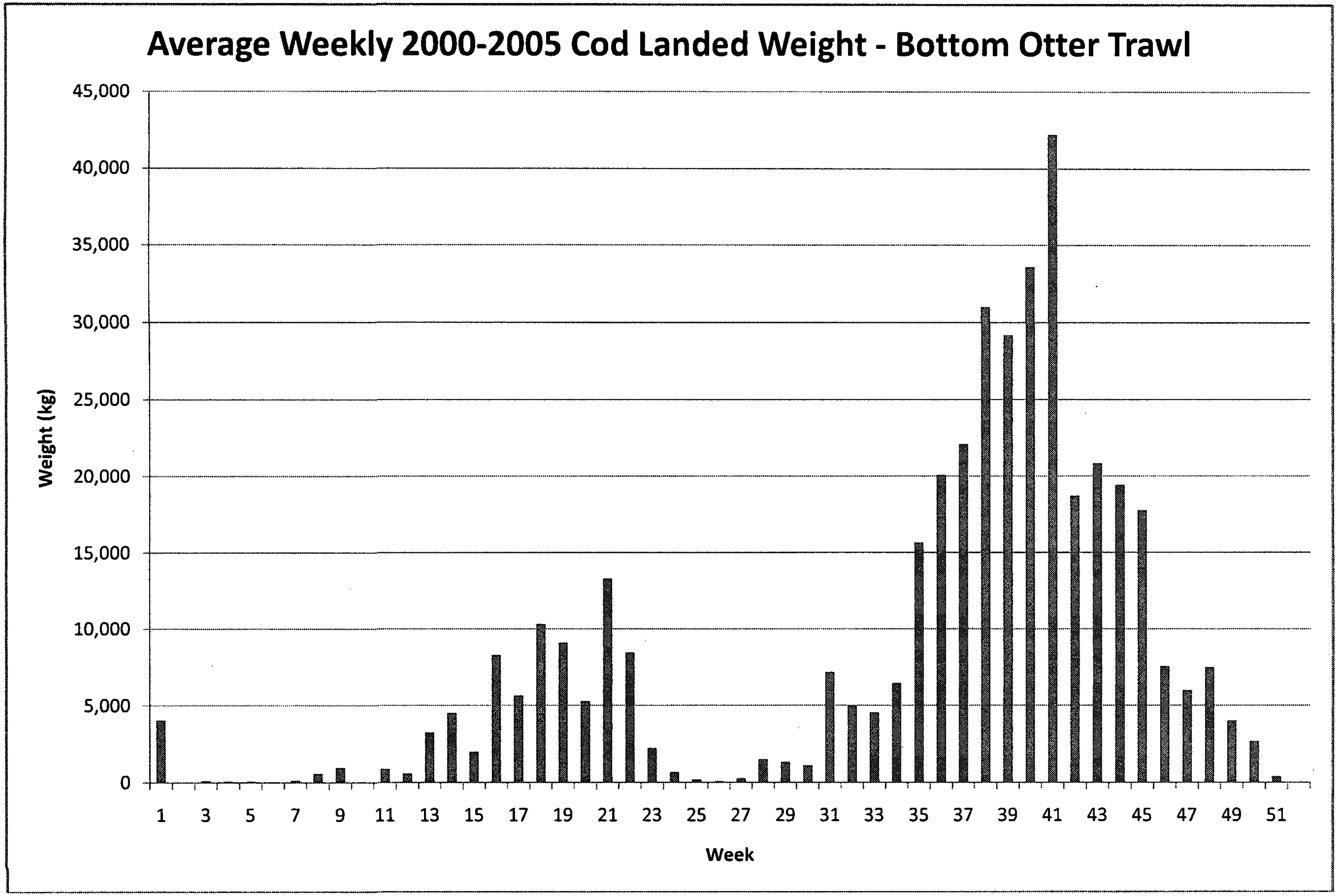

Figure A.10.1 Average Weekly Cod Landed Weight – Bottom Otter Trawl. Years 2000-2005.

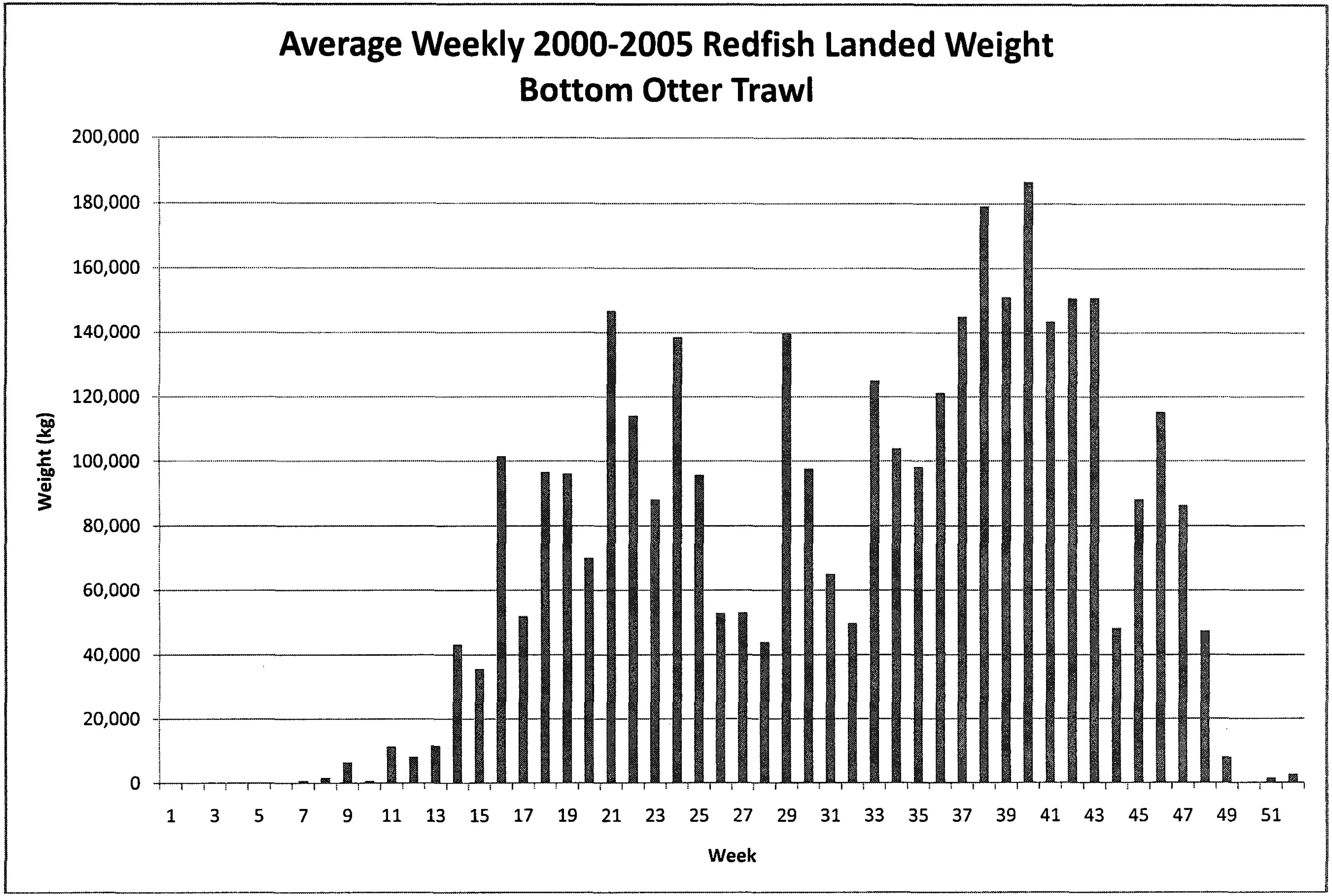

Figure A.10.2 Average Weekly Redfish Landed Weight – Bottom Otter Trawl. Years 2000-2005.

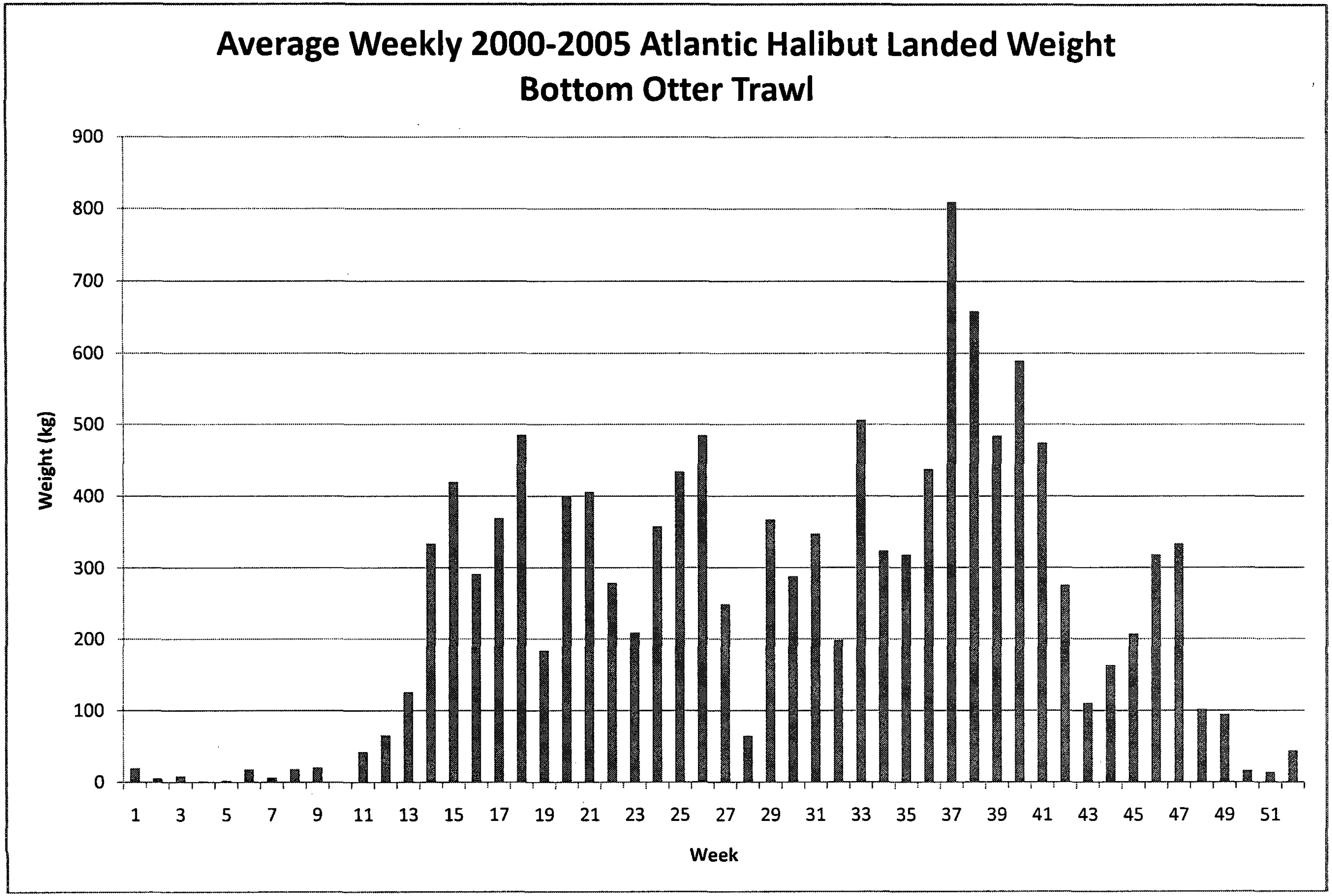

Figure A.10.3 Average Weekly Atlantic Halibut Landed Weight – Bottom Otter Trawl. Years 2000-2005.

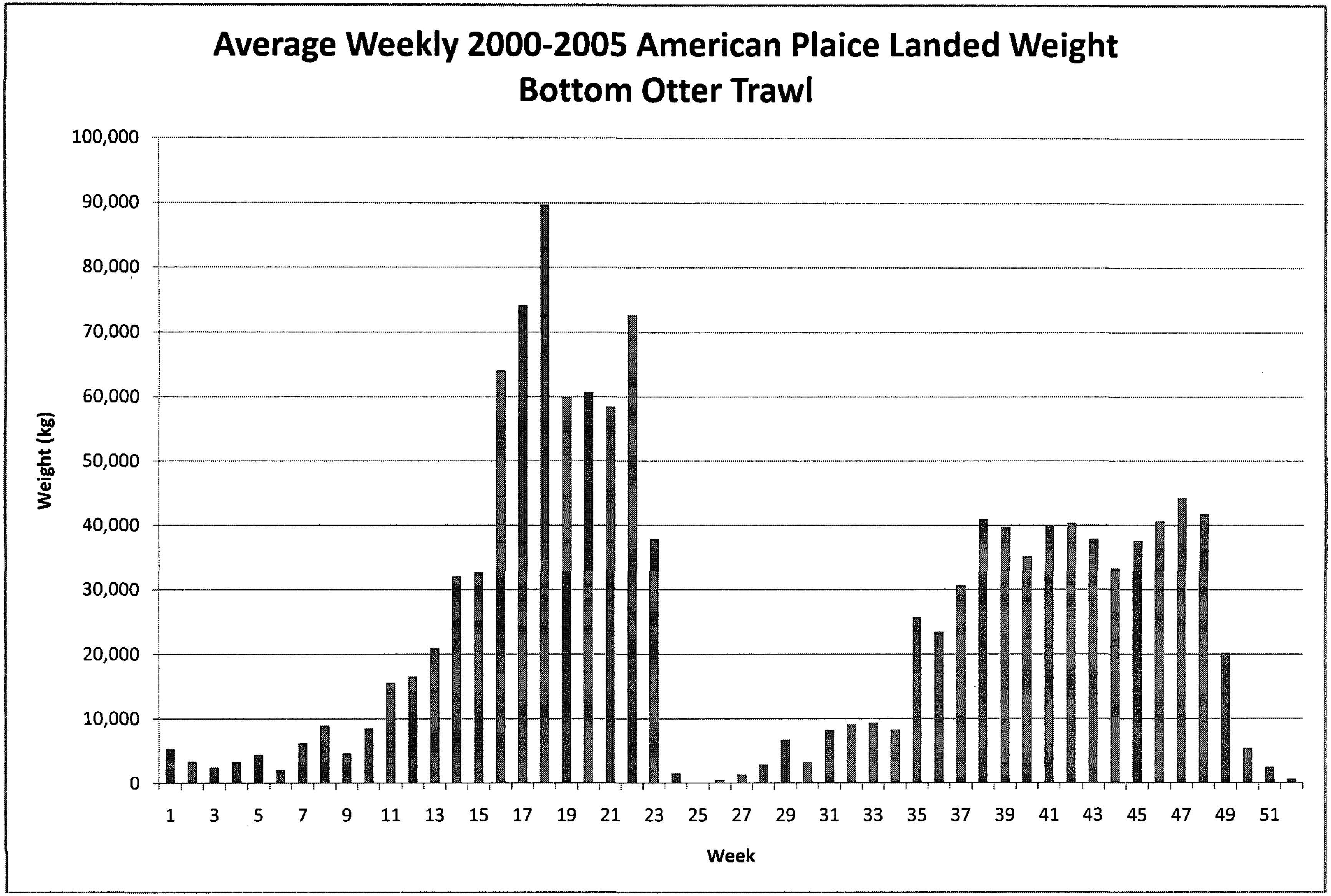

Figure A.10.4 Average Weekly American Plaice Landed Weight – Bottom Otter Trawl. Years 2000-2005.

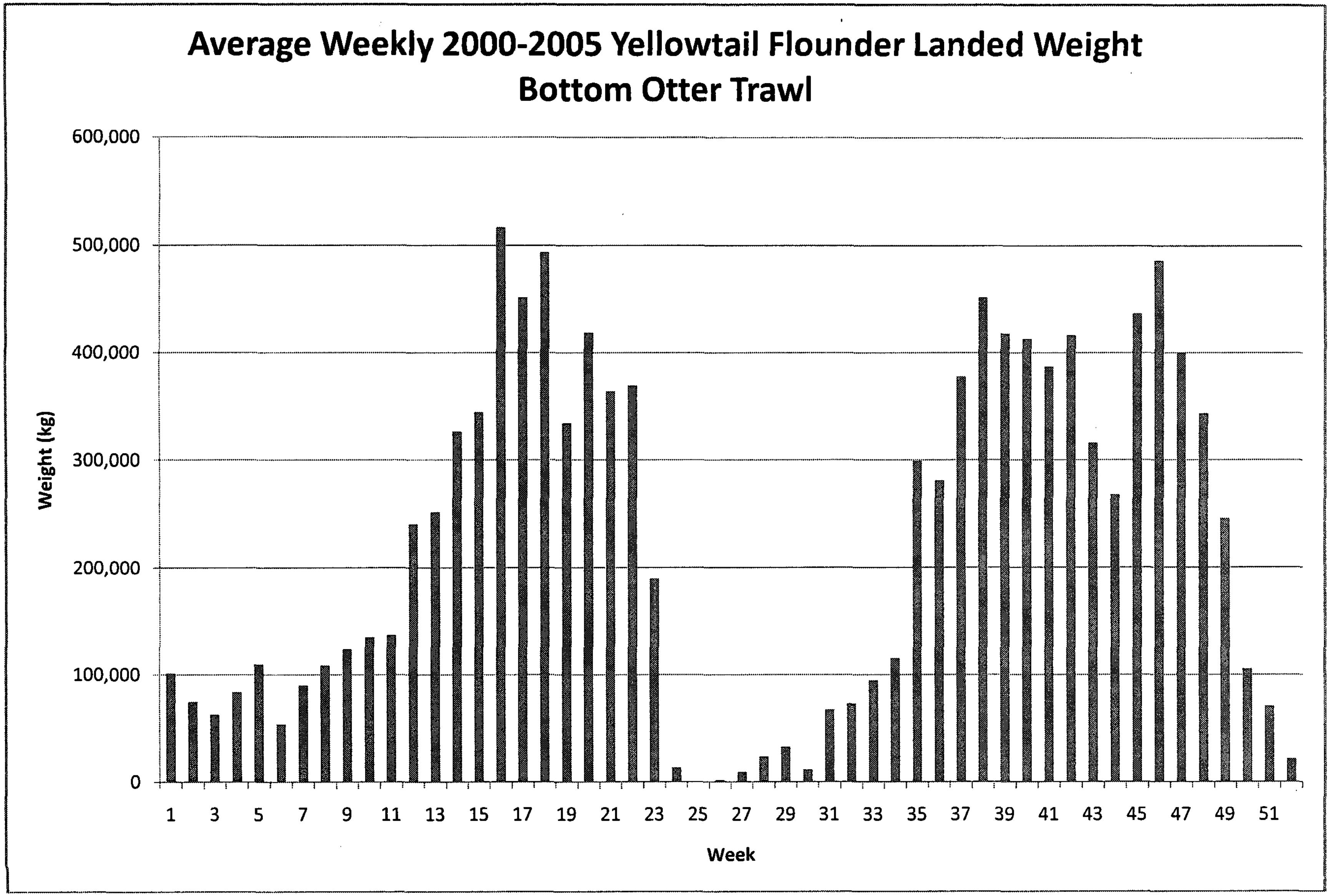

Figure A.10.5 Average Weekly Yellowtail Flounder Landed Weight – Bottom Otter Trawl. Years 2000-2005.

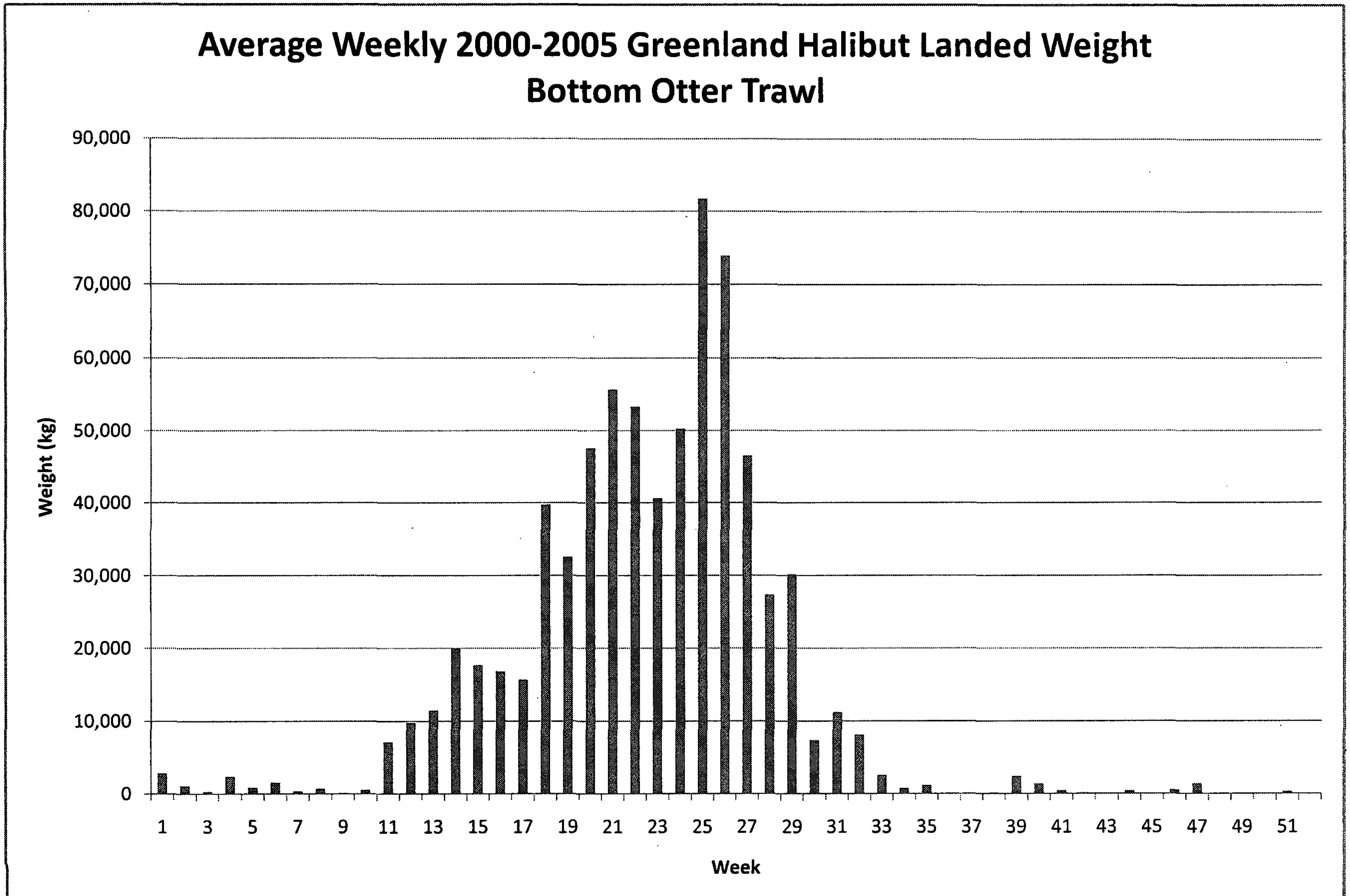

Figure A.10.6 Average Weekly Greenland Halibut Landed Weight – Bottom Otter Trawl. Years 2000-2005.

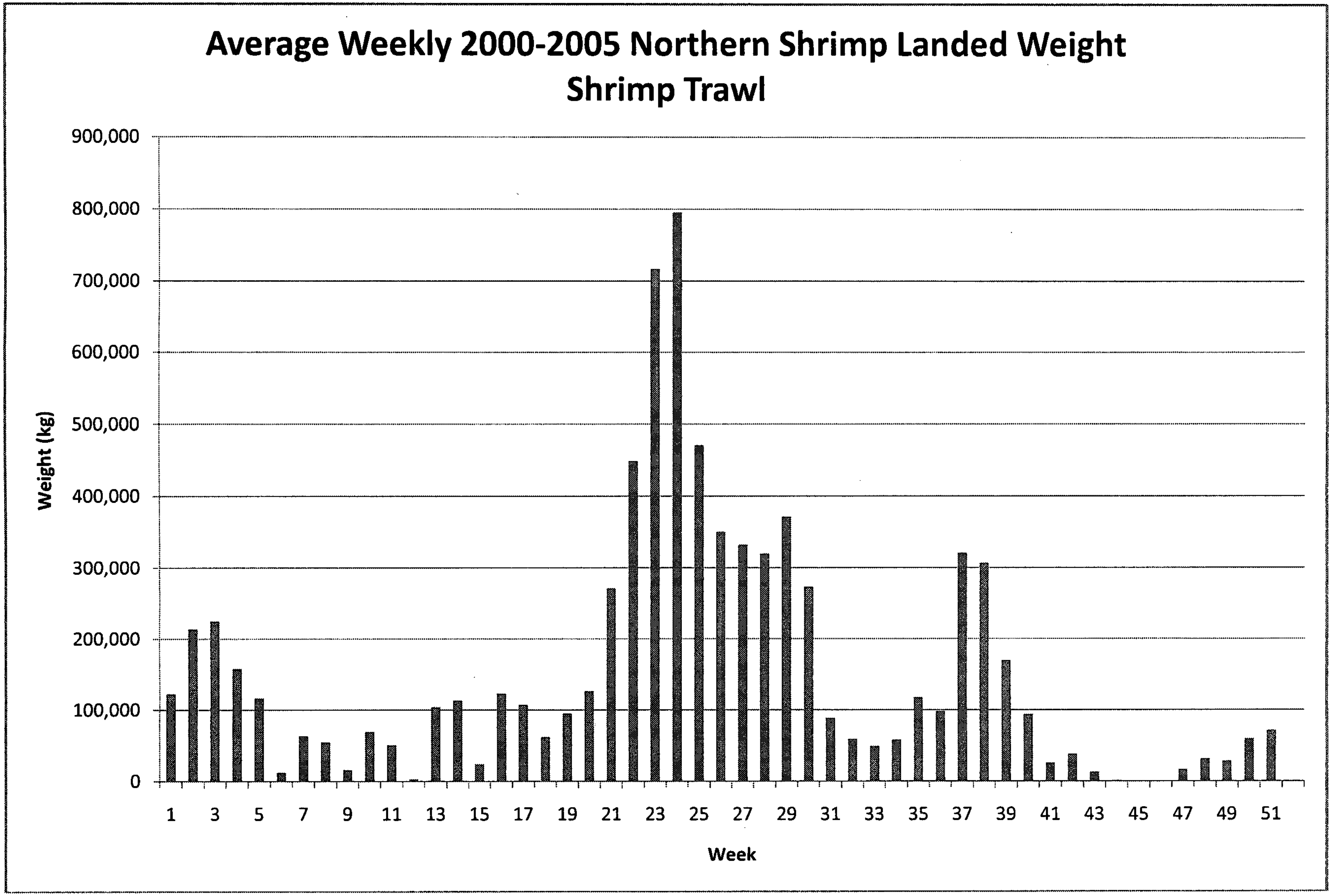

Figure A.10.7 Average Weekly Northern Shrimp Landed Weight – Shrimp Trawl. Years 2000-2005.

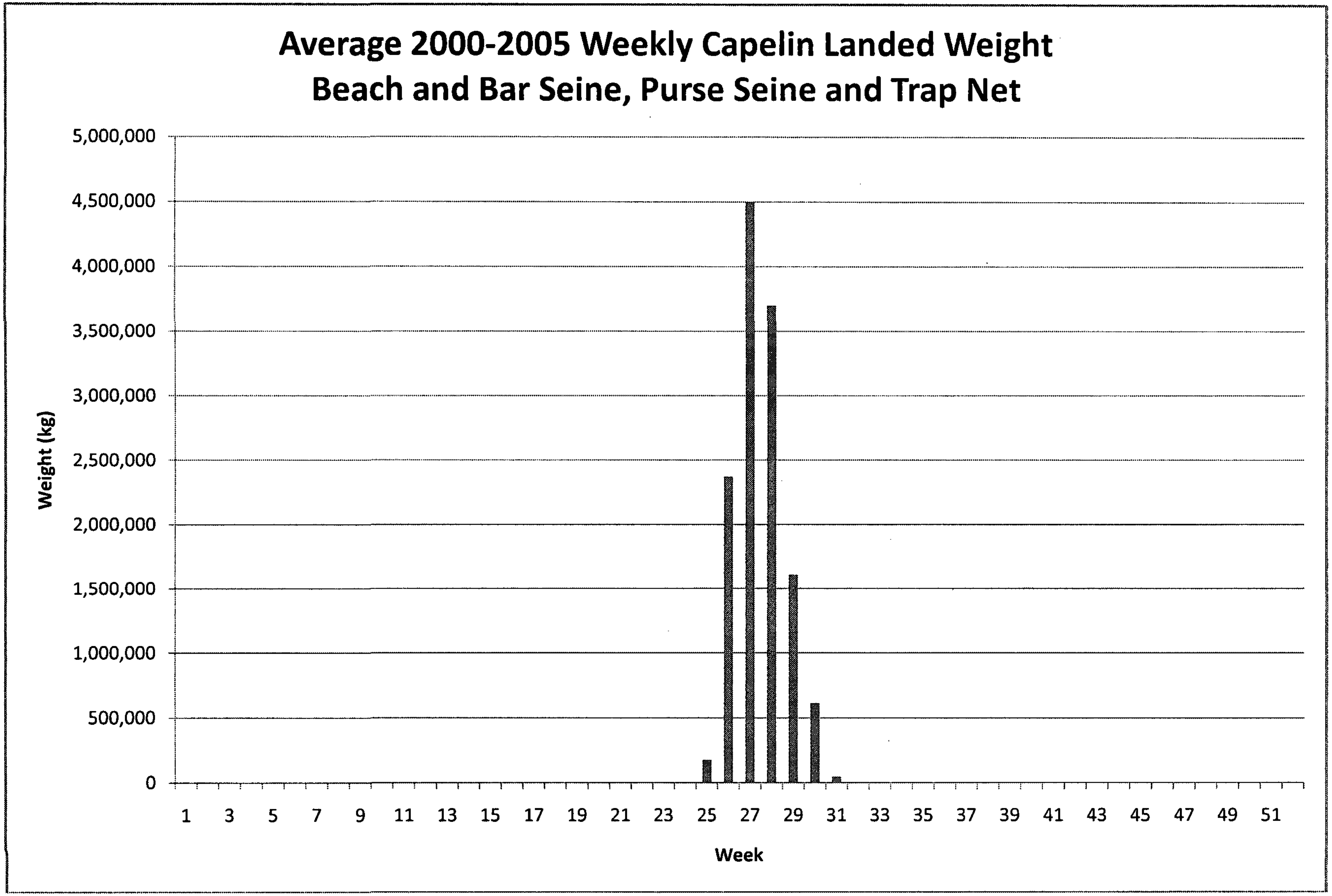

Figure A.10.8 Average Weekly Capelin Landed Weight – Beach and Bar Seine, Purse Seine and Trap Net. Years 2000-2005.

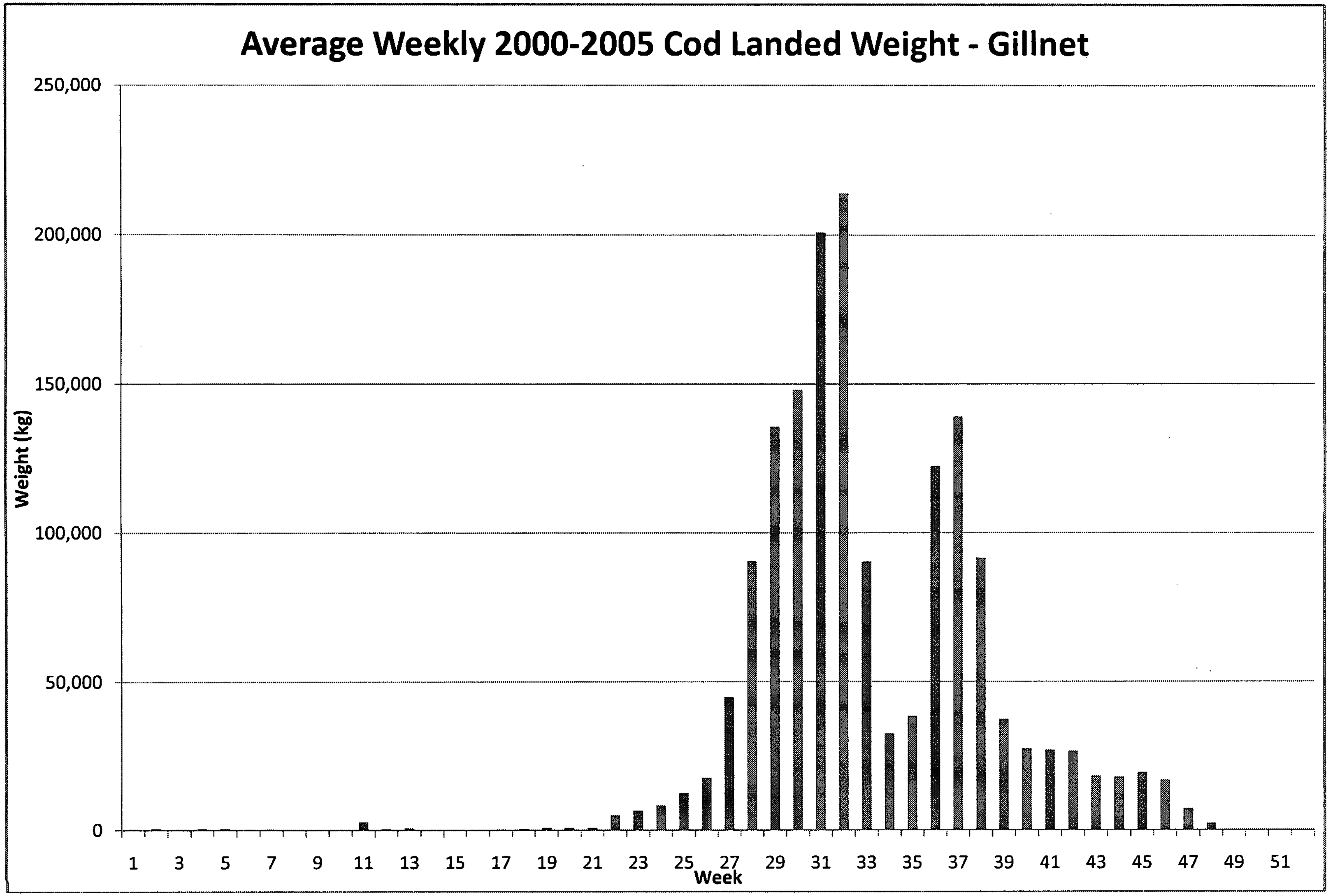

Figure A.10.9 Average Weekly Cod Landed Weight – Gillnet. Years 2000-2005.

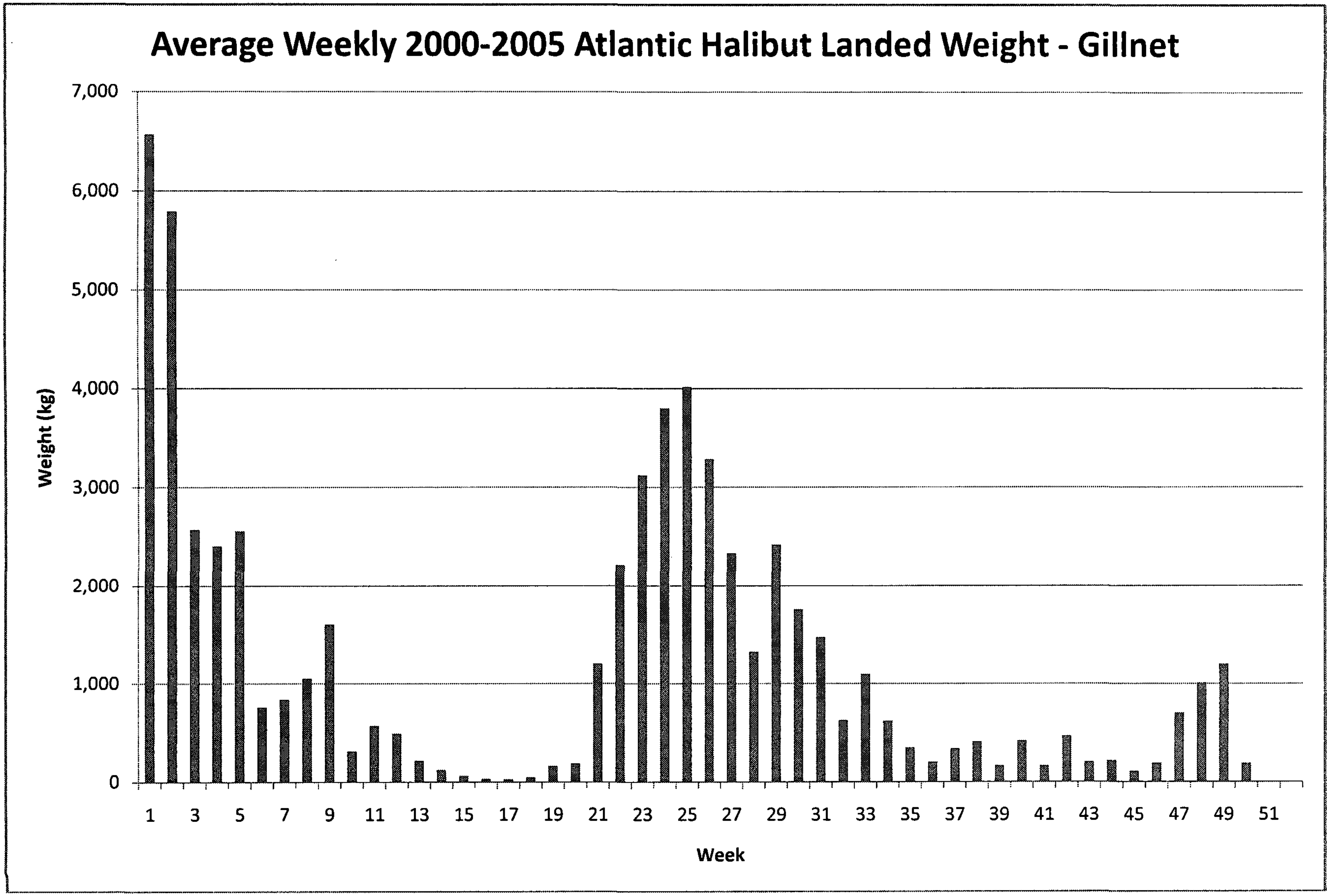

Figure A.10.10 Average Weekly American Plaice Landed Weight – Gillnet. Years 2000-2005.

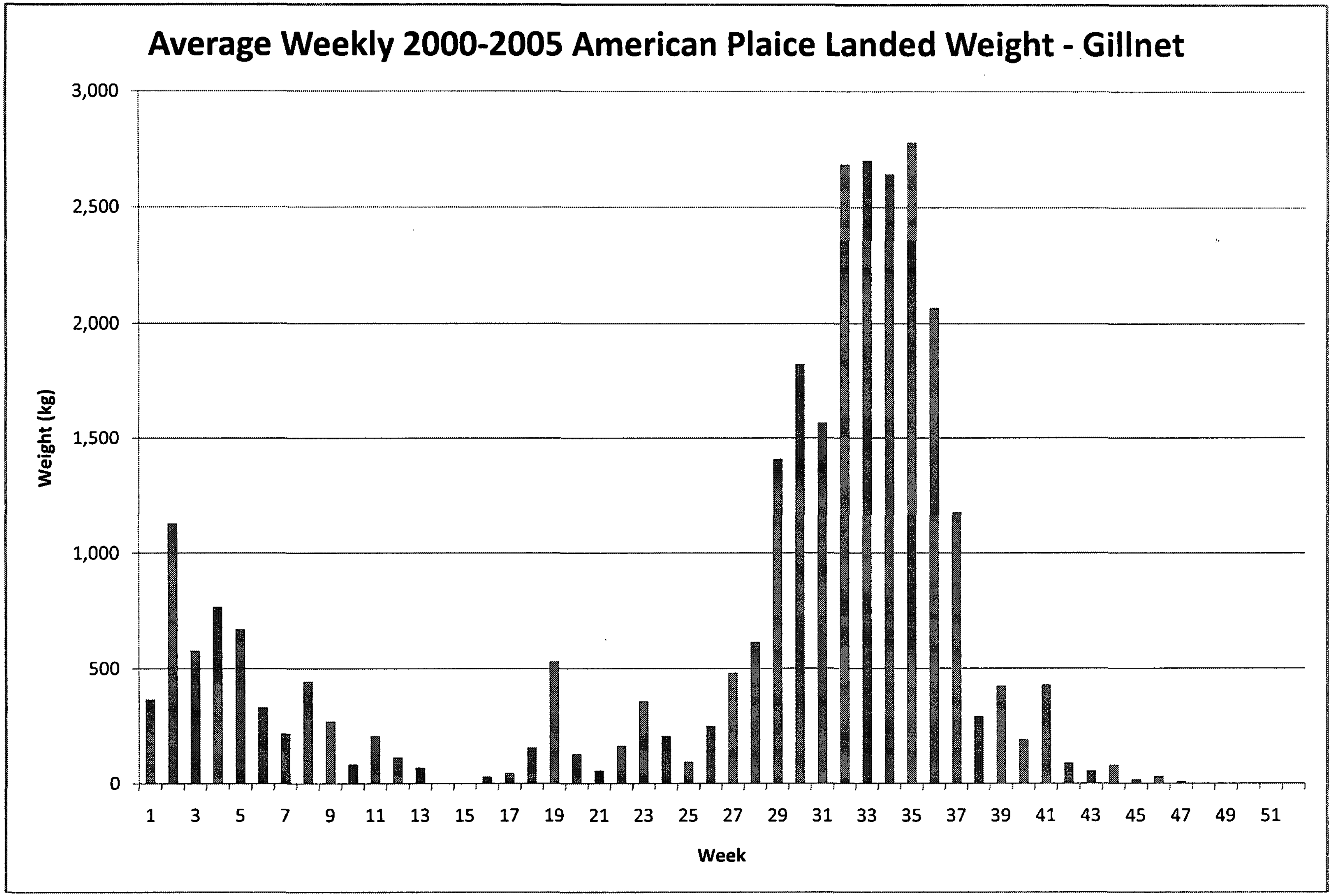

Figure A.10.11 Average Weekly Greenland Halibut Landed Weight – Gillnet. Years 2000-2005.

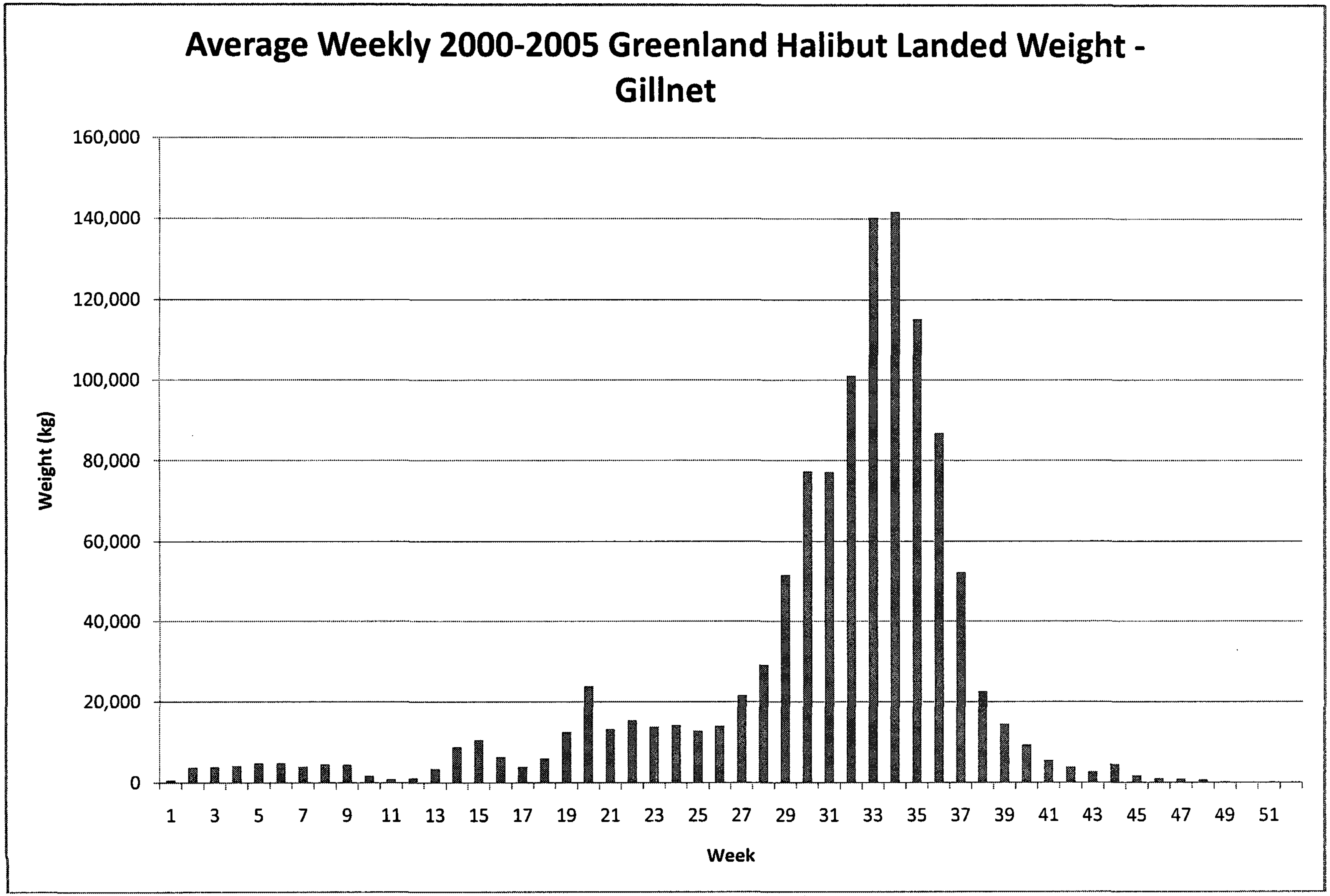

Figure A.10.12 Average Weekly Monkfish Landed Weight – Gillnet. Years 2000-2005.

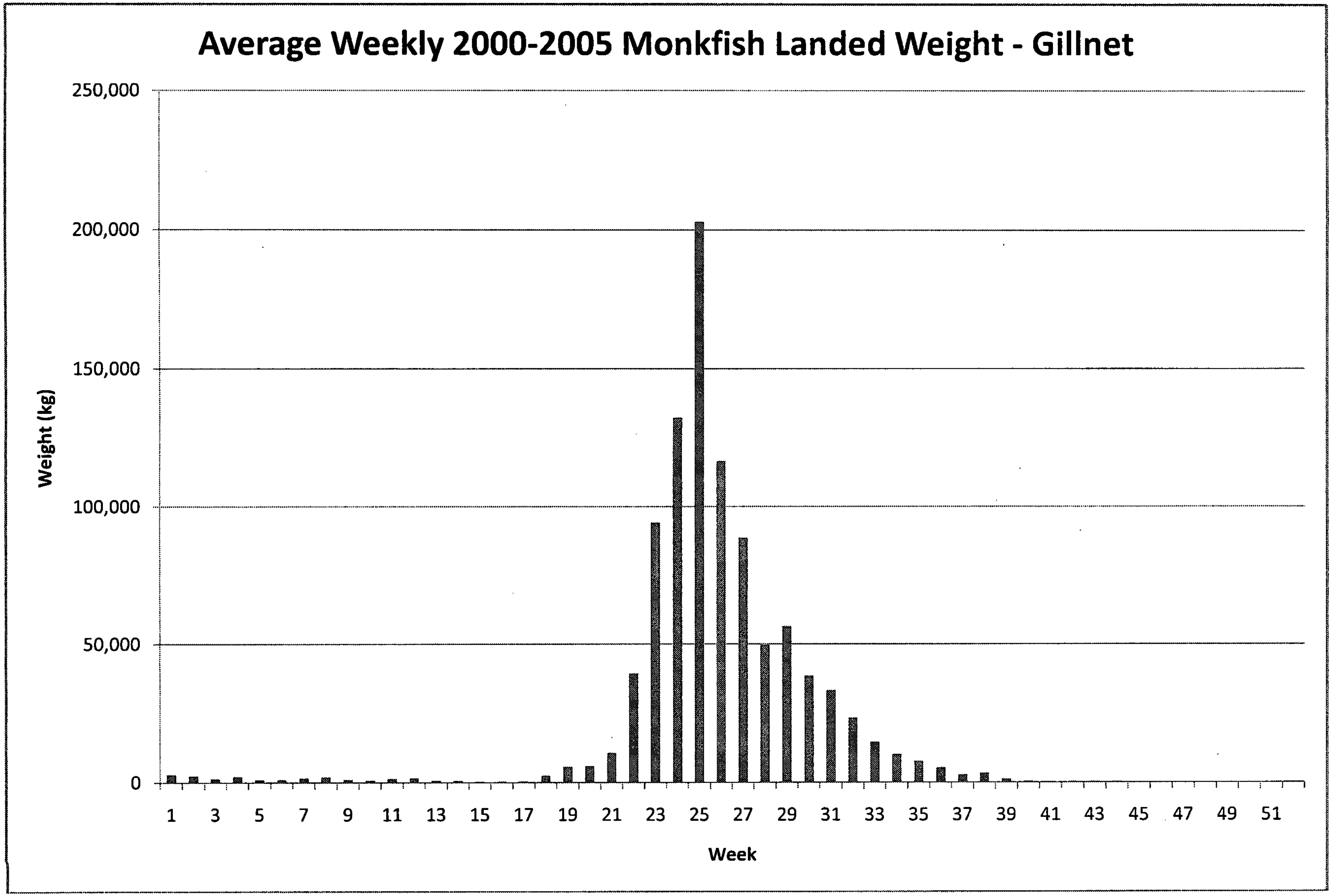

Figure A.10.13 Average Weekly Lumpfish Landed Weight – Gillnet. Years 2000-2005.

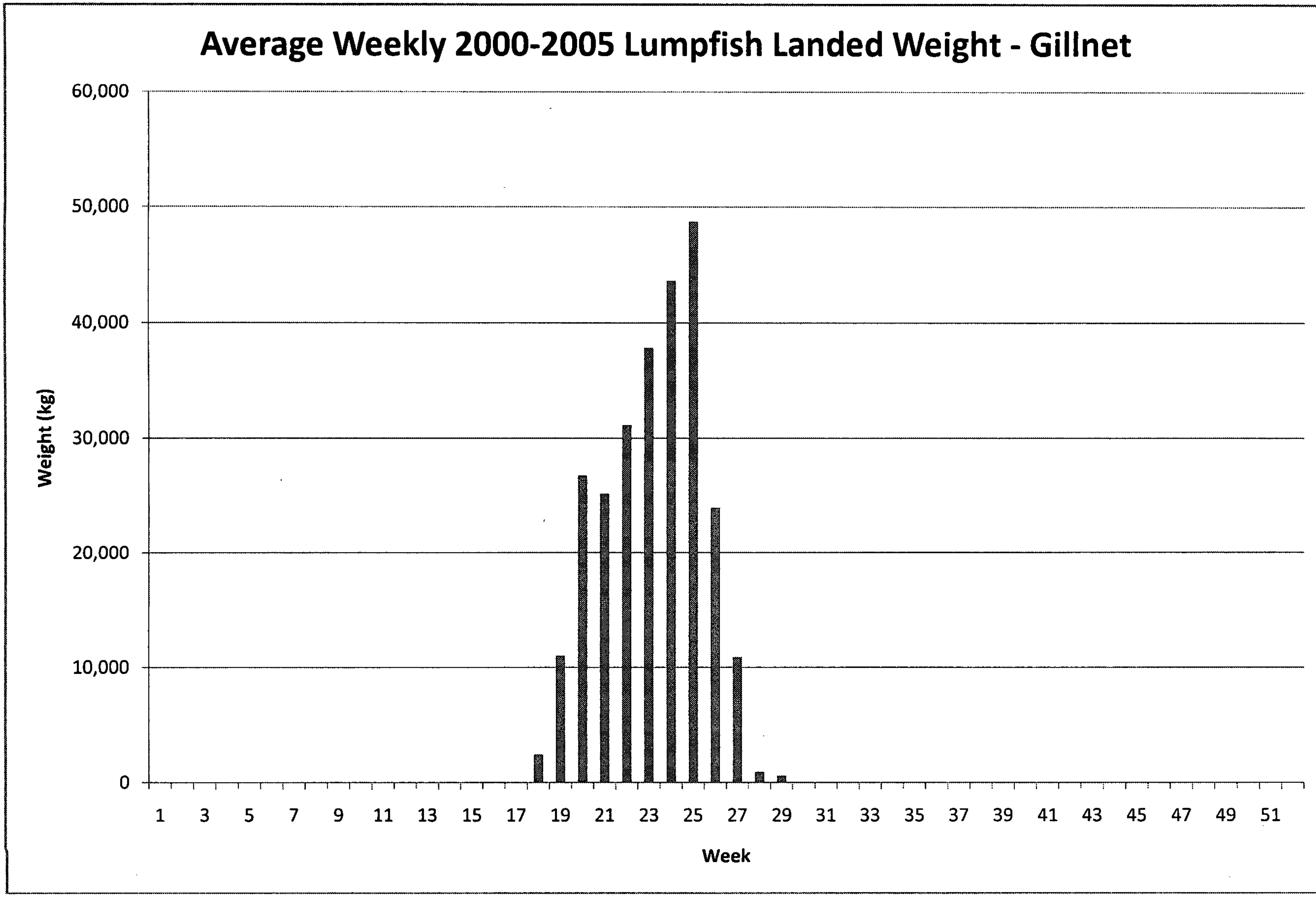

Figure A.10.14 Average Weekly Cod Landed Weight – Gillnet. Years 2000-2005.

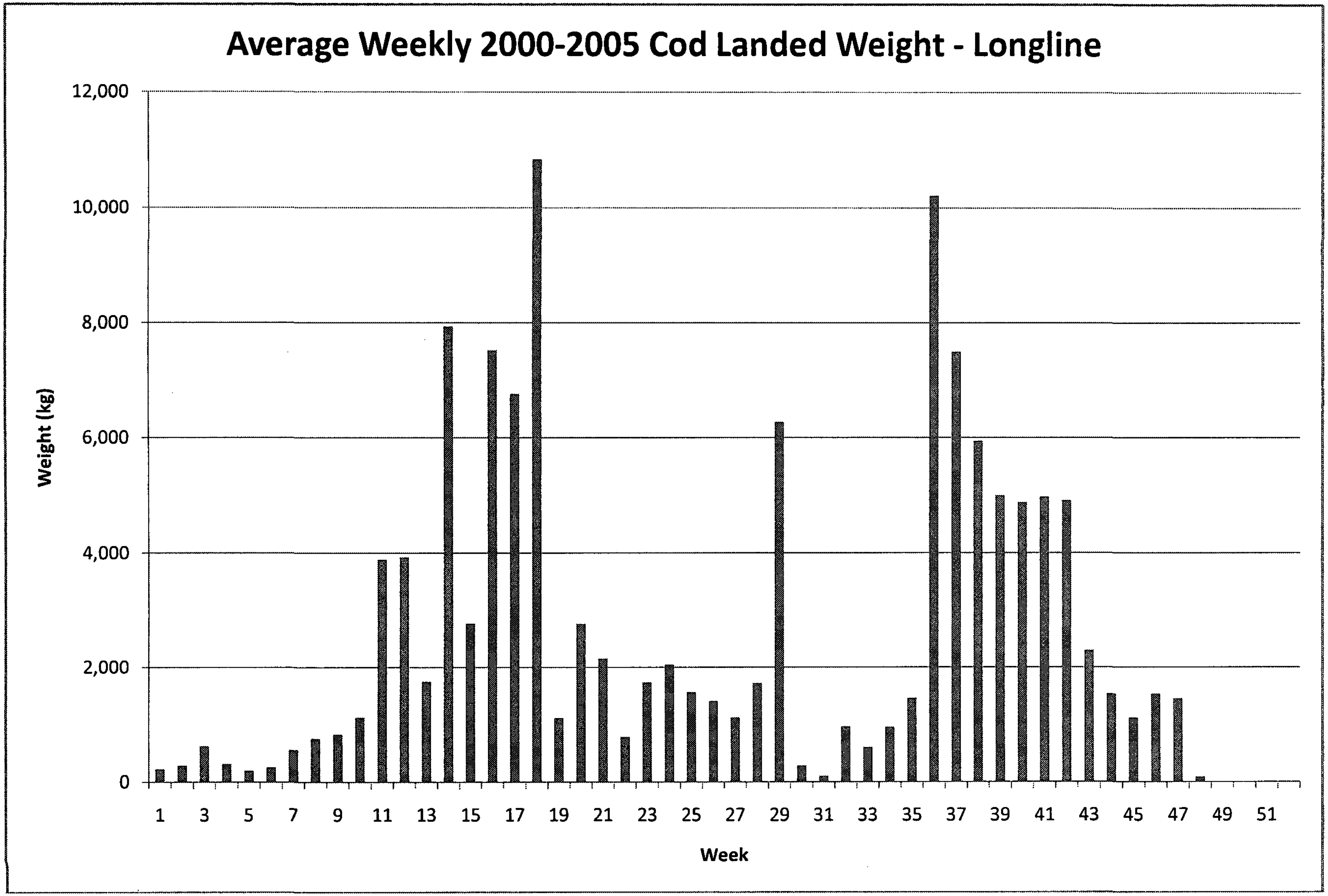

Figure A.10.15 Average Weekly Cod Landed Weight – Longline. Years 2000-2005.

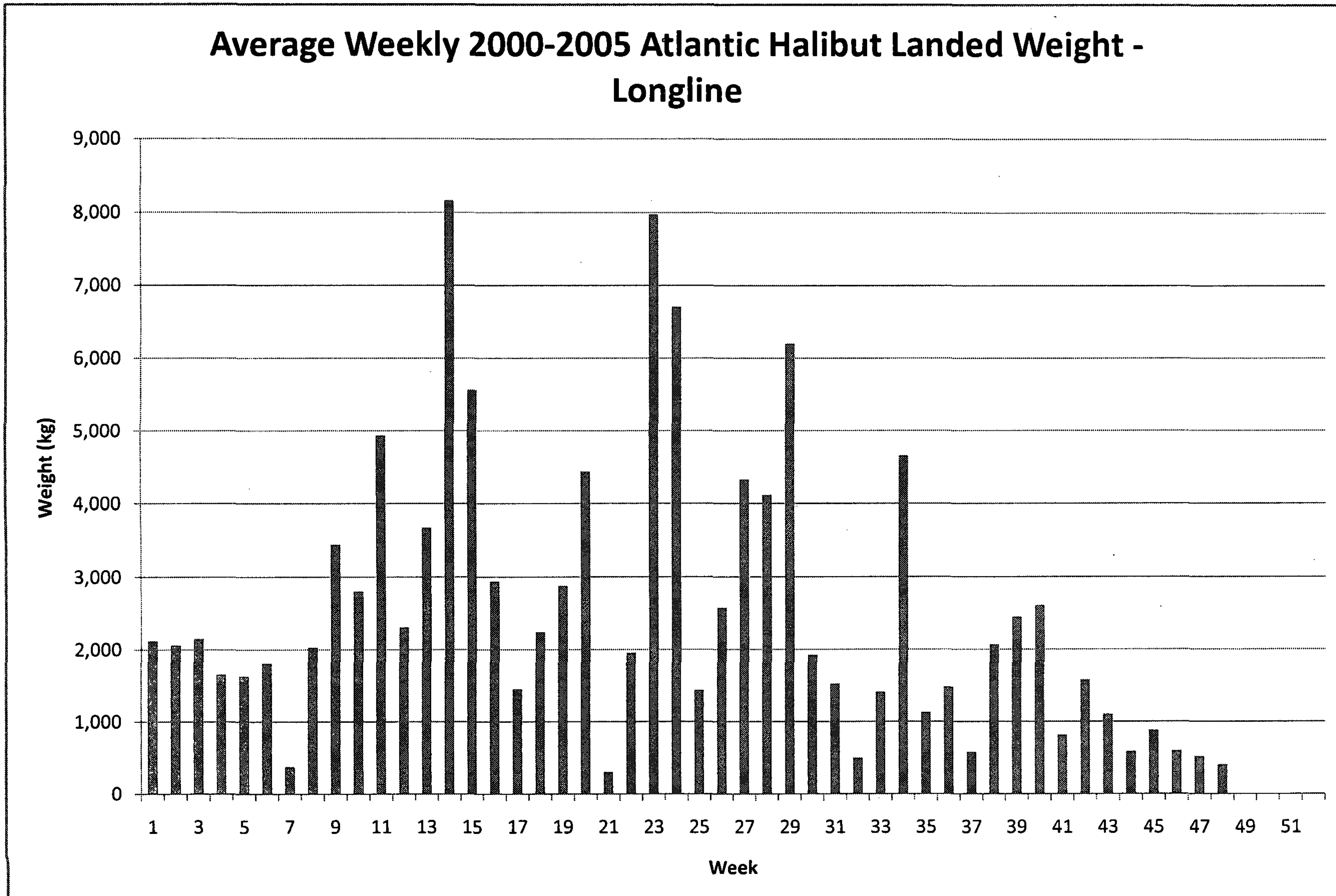

Figure A.10.16 Average Weekly Atlantic Halibut Landed Weight – Longline. Years 2000-2005.

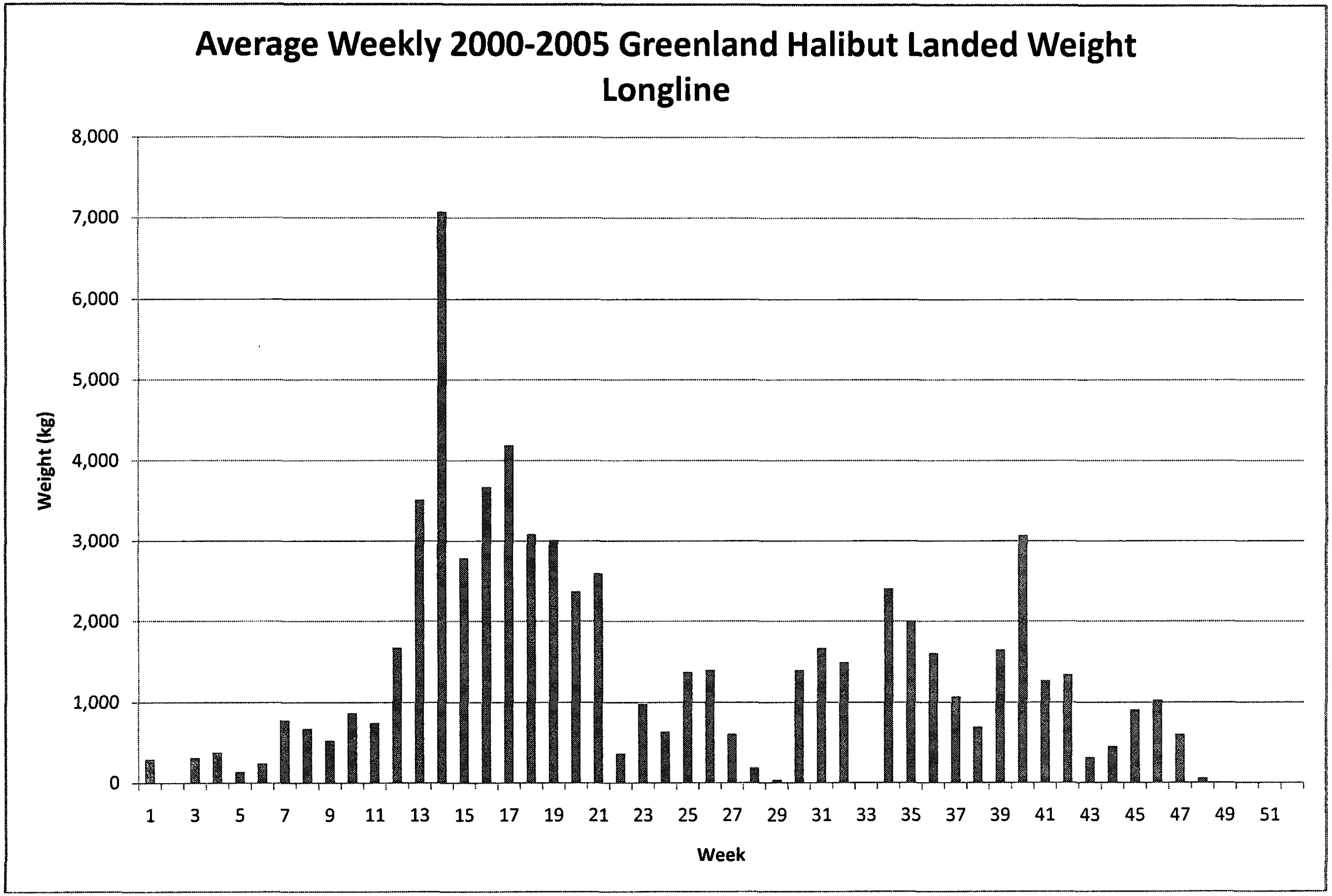

Figure A.10.17 Average Weekly Greenland Halibut Landed Weight – Longline. Years 2000-2005.

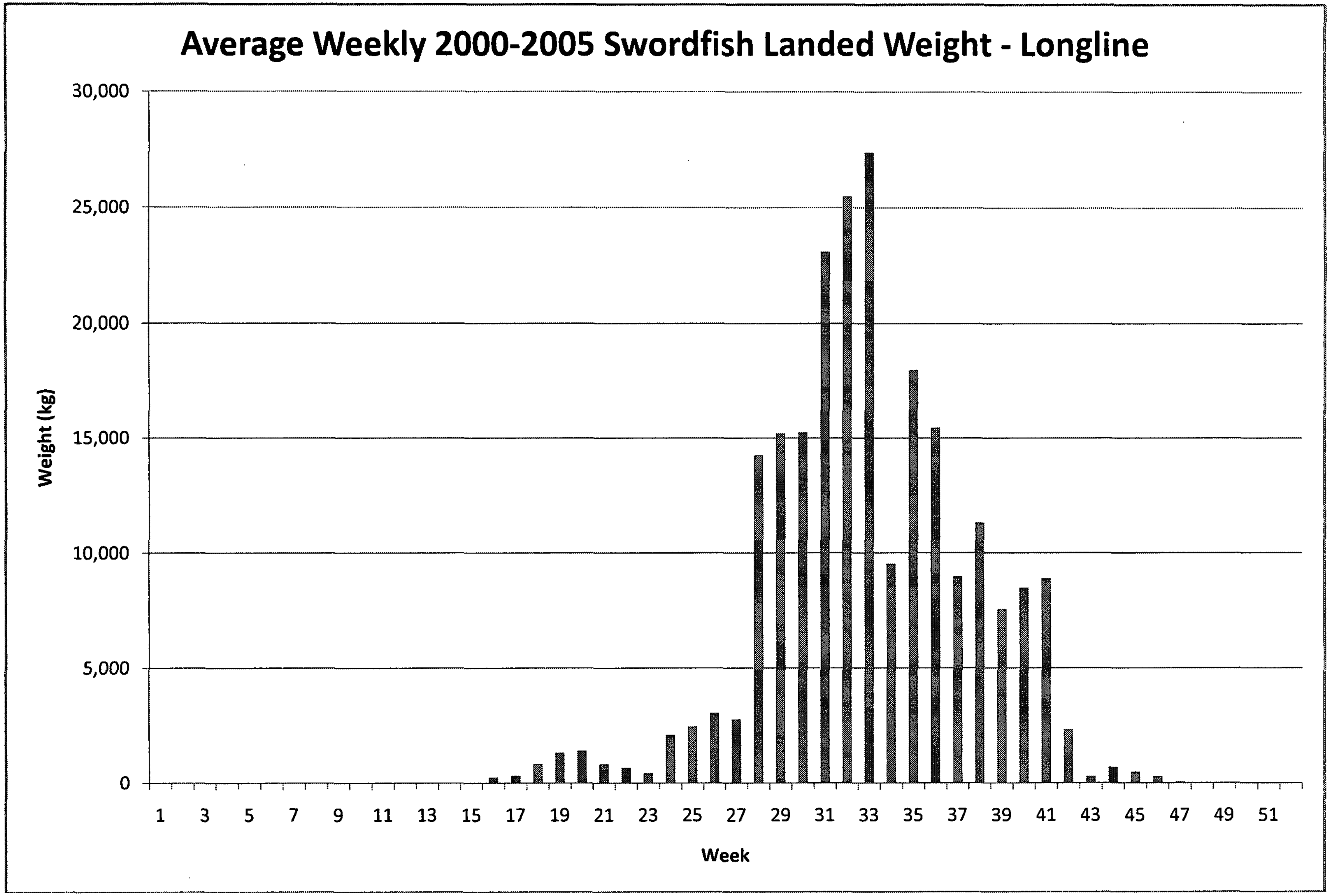

Figure A.10.18 Average Weekly Swordfish Landed Weight – Longline. Years 2000-2005.

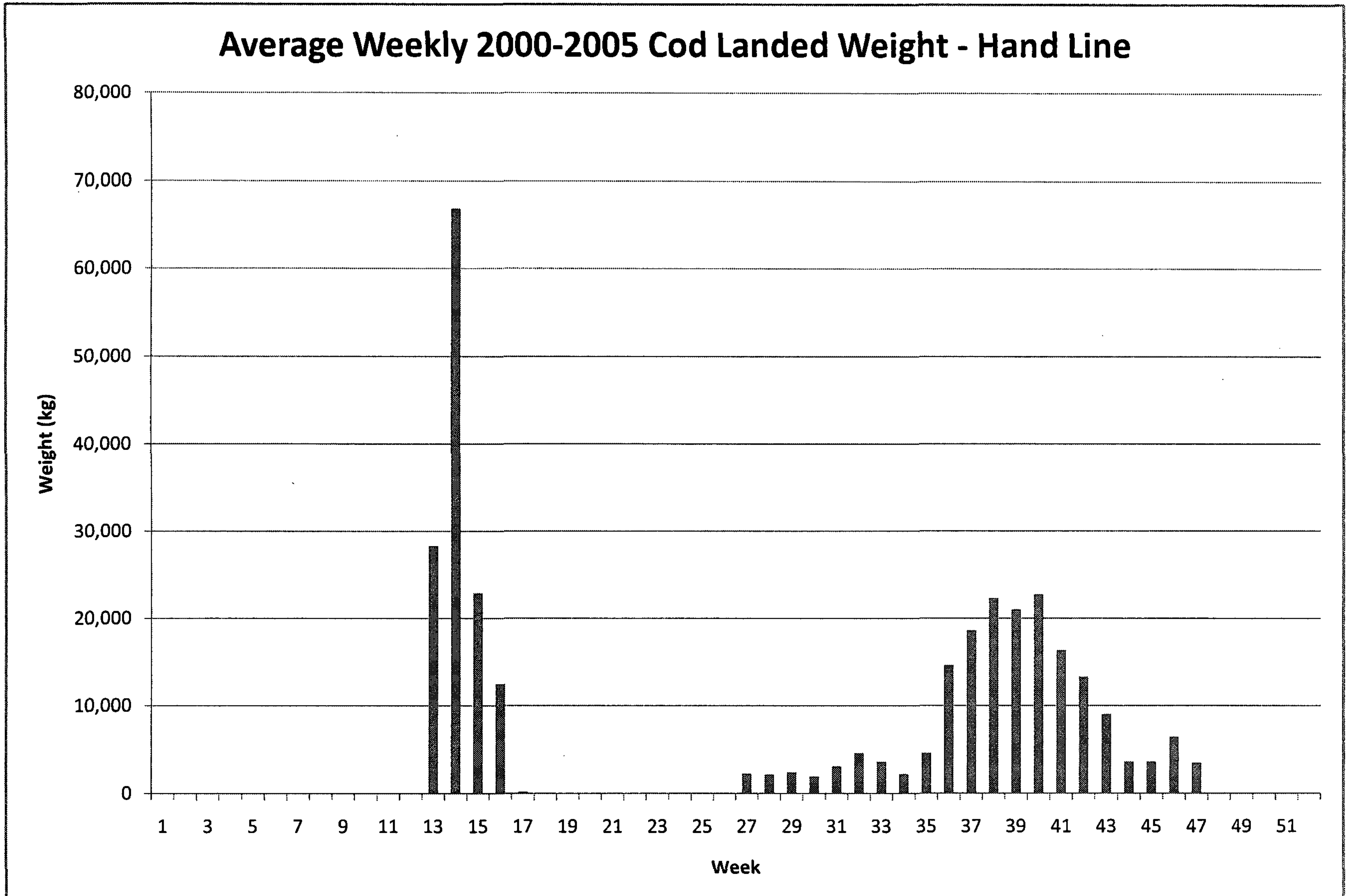

Figure A.10.19 Average Weekly Cod Landed Weight – Hand Line. Years 2000-2005.

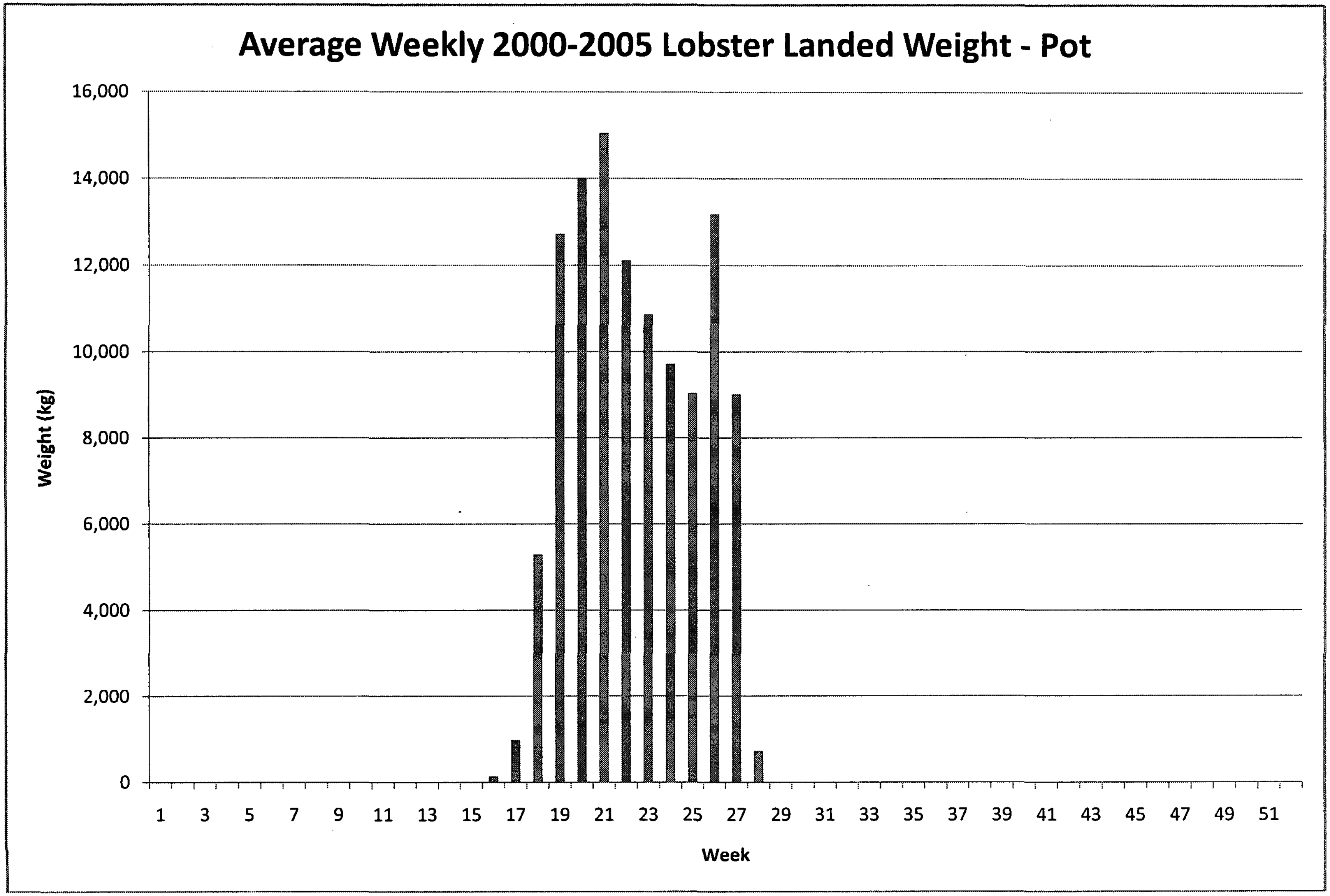

Figure A.10.20 Average Weekly Lobster Landed Weight – Pot. Years 2000-2005.

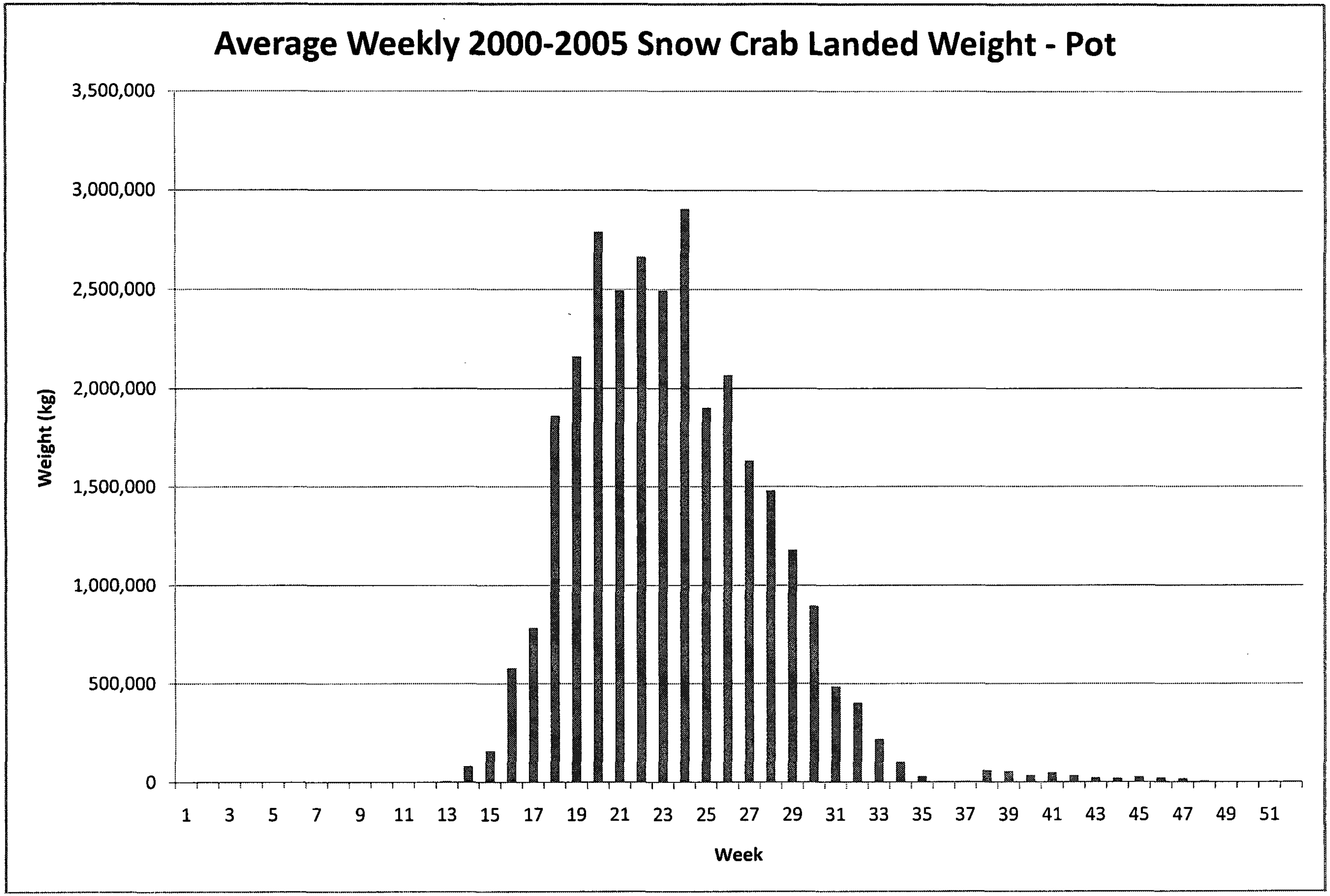

Figure A.10.21 Average Weekly Snow Crab Landed Weight – Dredge. Years 2000-2005.

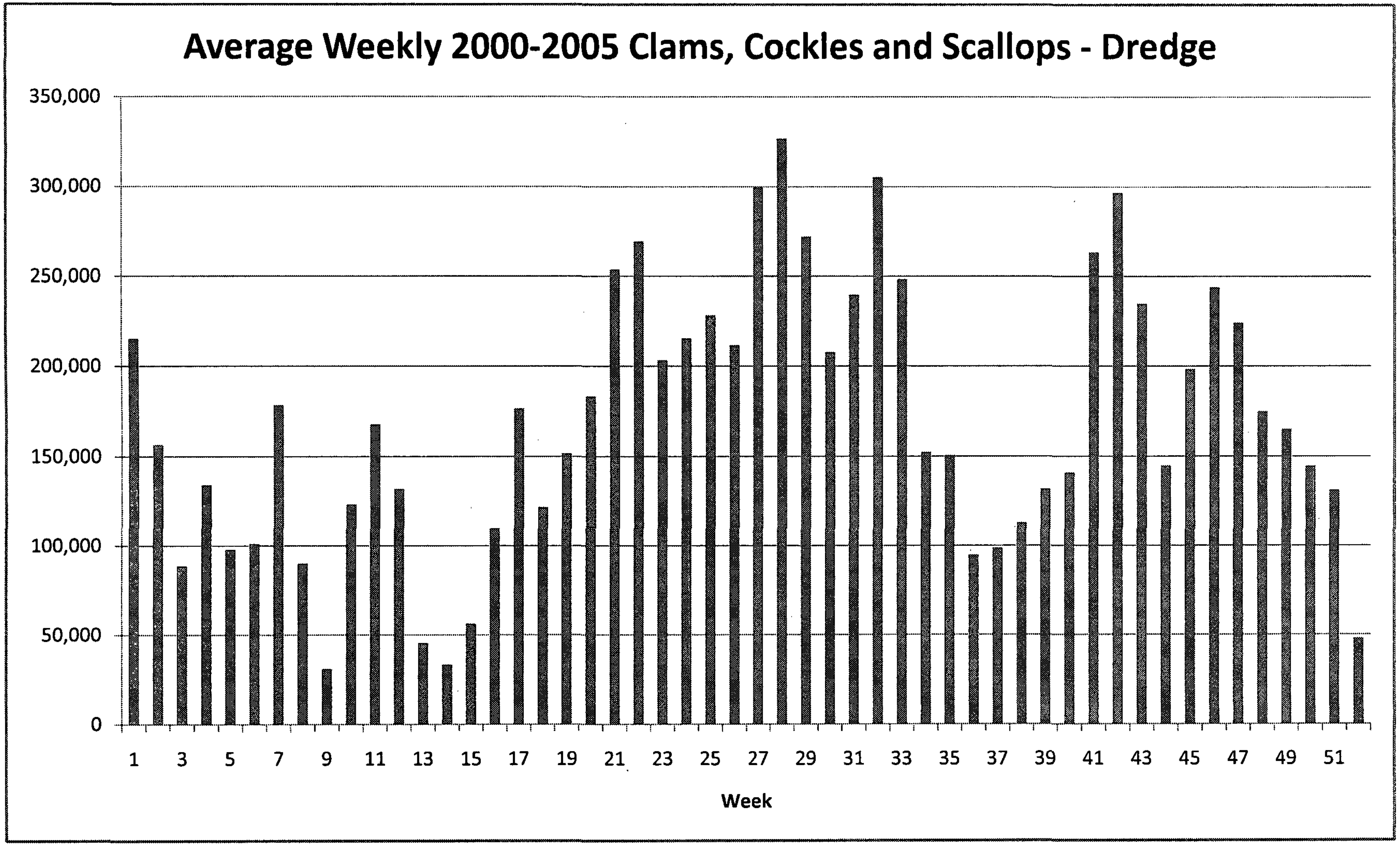

Figure A.10.22 Average Weekly Clams, Cockles and Scallops Landed Weight – Dredge. Years 2000-2005.

A.10.1 Weekly Catches Correlation Analysis

After identifying the main seasons of activity for each species and gear type, it is necessary to ensure they are representative of the annual activity for each individual year from 2000 to 2005. Example of weekly catch correlation analysis is shown in Table A.10.1 and Table A.10.2

The high correlation coefficients support the use of weekly catch weight by area to drive the model.

Table A.10.1 Correlation Analysis of Weekly Snow Crab Catches in Area 3Nb

Snow Crab	2005	2004	2003	2002	2001	2000
2005	1					
2004	0.78	1				
2003	0.36	0.65	1			
2002	0.50	0.75	0.88	1		
2001	0.80	0.82	0.45	0.61	1	
2000	0.71	0.77	0.75	0.78	0.64	1

Table A.10.2 Correlation Analysis of Weekly Lobster Catches in Area 3Lb

Lobster	2005	2004	2003	2002	2001	2000
2005	1					
2004	0.92	1				
2003	0.66	0.81	1			
2002	0.93	0.93	0.73	1		
2001	0.79	0.86	0.88	0.76	1	
2000	0.72	0.72	0.63	0.72	0.79	1

A.11 Data Analysis Results

The complete specification of location and time of activity for each species and gear type combination is listed in Table A.11.1 and concludes our data analysis.

Table A.11.1Main Location and Time of Activity for each Gear Type and Species Combination

Gear Type	Species	Subdivisions	Weeks
Bottom Otter Trawl	Cod	3Na, 3Nc, 3Ob, 3Oc, 3Od, 3Oe	1, 13 to 23, 31 to 50
	Redfish	3Oa, 3Oc, 3Od, 3Oe	14 to 48
	Atlantic Halibut	3Ld, 3Nc, 3Oa, 3Oc, 3Od, 3Oe	12 to 49
	American Plaice	3Ld, 3Lr, 3Na, 3Nc, 3Ob, 3Od	11 to 23, 35 to 39
	Yellowtail Flounder	3Lr, 3Na, 3Nc, 3Ob, 3Od	1 to 23, 31 to 51
	Greenland Halibut	3Ld	11 to 32
Shrimp Trawl	Northern Shrimp	3Lc, 3Ld, 3Le, 3Li	1 to 5, 13 to 30, 35 to 40
Beach and Bar Seine, Purse Seine and Trap Net	Capelin	3La, 3Lb, 3Lf	26 to 30
Gillnet	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq	27 to 46
	Atlantic Halibut	3Oa, 3Oc, 3Od, 3Oe	1 to 9, 21 to 33,
	American Plaice	3La, 3Lb, 3Lc, 3Ld, 3Lf, 3Oc, 3Od, 3Oe	1 to 9, 19 to 41
	Greenland Halibut	3La, 3Lb, 3Lc, 3Ld, 3Le, 3Oa, 3Oc, 3Oe	19 to 40
	Monkfish	3Oa, 3Oc, 3Od, 3Oe	22 to 32
	Lumpfish	3La, 3Lb, 3Lf,	19 to 27
Longline	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq, 3Nc, 3Oa, 3Oc, 3Od, 3Oe	11 to 29, 36 to 47
	Atlantic Halibut	3Lt, 3Nc, 3Nf, 3Oa, 3Oc, 3Od, 3Oe	1 to 43
	Greenland Halibut	3Li, 3Oc, 3Oe	12 to 26, 30 to 46
	Swordfish	3Nd, 3Nf, 3Oc, 3Od, 3Oe	28 to 41
Handline	Cod	3La, 3Lb, 3Lf, 3Lj, 3Lq	13 to 16
Pot	Lobster	3La, 3Lb, 3Lf, 3Lq	18 to 28
	Snow Crab	3La, 3Lb, 3Lc, 3Ld, 3Le, 3Lg, 3Lh, 3Li, 3Lj, 3Lq, 3Lt, 3Nb, 3Ne, 3Oa, 3Ob	15 to 33
Dredge	Clams, Cockles and Scallops	3Na, 3Nb, 3Nd	Year-round

A.12 Cost Structure

Implementing the model requires specifications on the catch, i.e. its location, time period, gear type, landed weight and landed value. These items have already been addressed in this chapter. Next in the requirements needed for the model are the costs associated with operating fishing vessels. Two sources are used to derive the values needed for the model implementation, DFO's 2004 Costs and Earnings Survey results and an internal report to DFO (Canada 2007i and Lane 2007). The former contains detailed information on the Newfoundland Crab and Shrimp vessels under 65' (19.8m) Length Overall (LOA). Values for Lobster and Capelin vessels under 65' LOA are derived from the Maritimes and the Bay of Fundy fleets, respectively. In the internal report, the cost structure is defined by three classes of vessel LOA; under 65', 65'to 100' (19.8m) and over 100'. Each is divided into fixed and mobile gear, except for vessels over 100' (30.5m). In the case where the vessel classes defined in Table A.12.1 contain more than one class defined in the report such as longline vessels over 65', the final value is the sum of the weighted components for each vessel class. For example, the average annual 2000-2005 catch by longline vessels of 65' to 100' LOA and by vessels over 100' LOA represent 72% and 28% of the total for all vessels over 65', respectively. Therefore cost components of each fleet segment are multiplied by their corresponding weight to derive the longline fleet cost structure for vessels over 65' LOA. In the table, "Other" includes food, bait and ice.

Table A.12.1 Grand Banks Fishing Fleet Cost Structure

Gear Type and Vessel LOA	Labour	Fuel, Oil and Grease	Other	Operating Cost to Revenue Ratio
Lobster < 25' (7.6 m)	0.69	0.09	0.23	0.47
Crab < 25'	0.65	0.14	0.21	0.47
Crab 25' to 65' (19.8m)	0.81	0.08	0.11	0.59
Crab > 65'	0.57	0.28	0.15	0.54
Dredge < 65'	0.75	0.14	0.11	0.53
Dredge > 65'	0.47	0.35	0.18	0.70
Capelin (All vessels)	0.74	0.10	0.17	0.47
Shrimp < 65'	0.64	0.25	0.11	0.56
Shrimp > 65'	0.47	0.35	0.18	0.70
Gillnet < 65'	0.74	0.10	0.17	0.47
Gillnet > 65'	0.35	0.37	0.28	0.61
Hand Line (All Vessels)	0.74	0.10	0.17	0.47
Longline < 65'	0.74	0.10	0.17	0.47
Longline > 65'	0.38	0.36	0.26	0.63
Bottom Otter Trawl < 100' (30.5m)	0.58	0.26	0.15	0.54
Bottom Otter Trawl > 100'	0.47	0.35	0.18	0.70

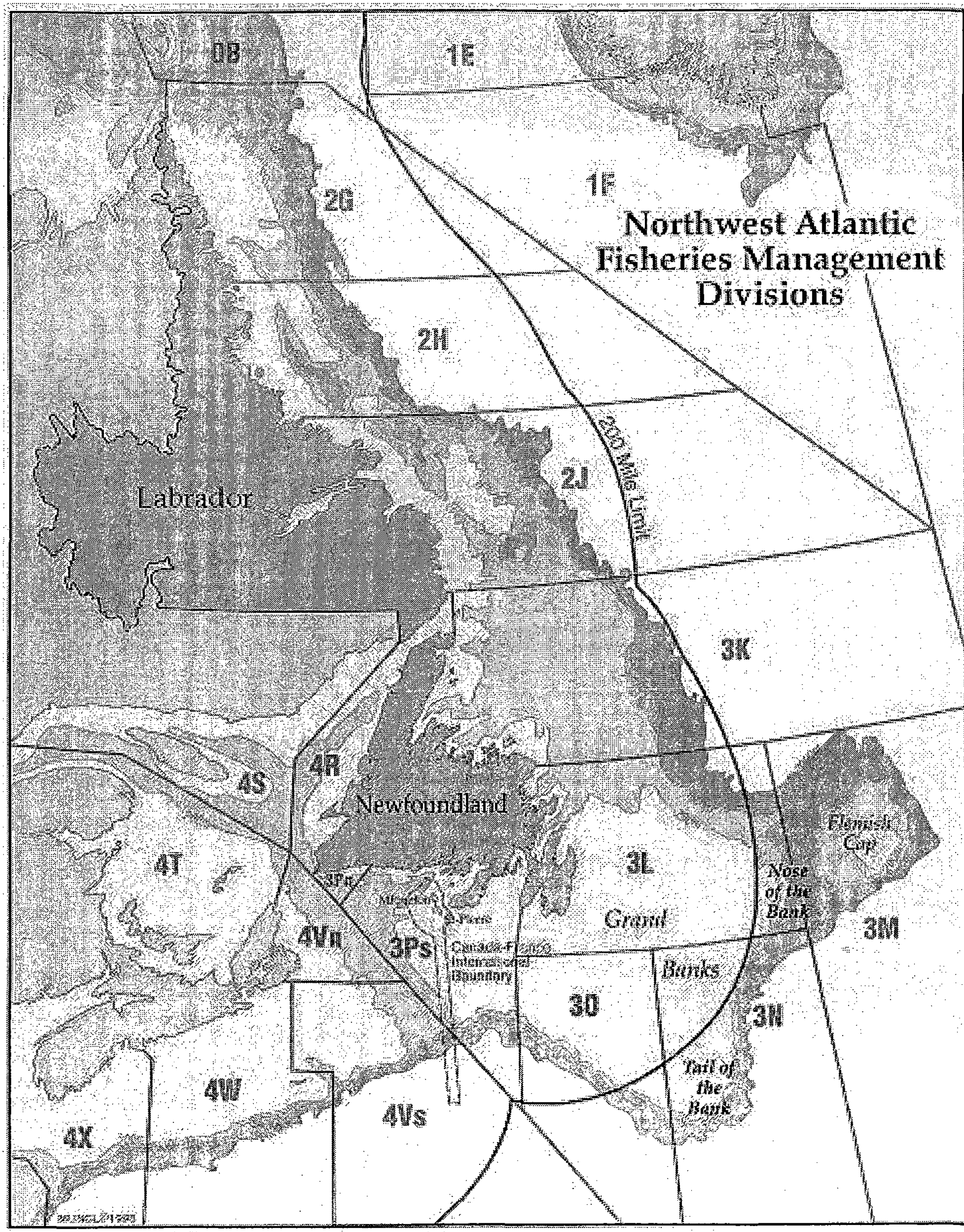

Figure A.12.1 NAFO Management Divisions

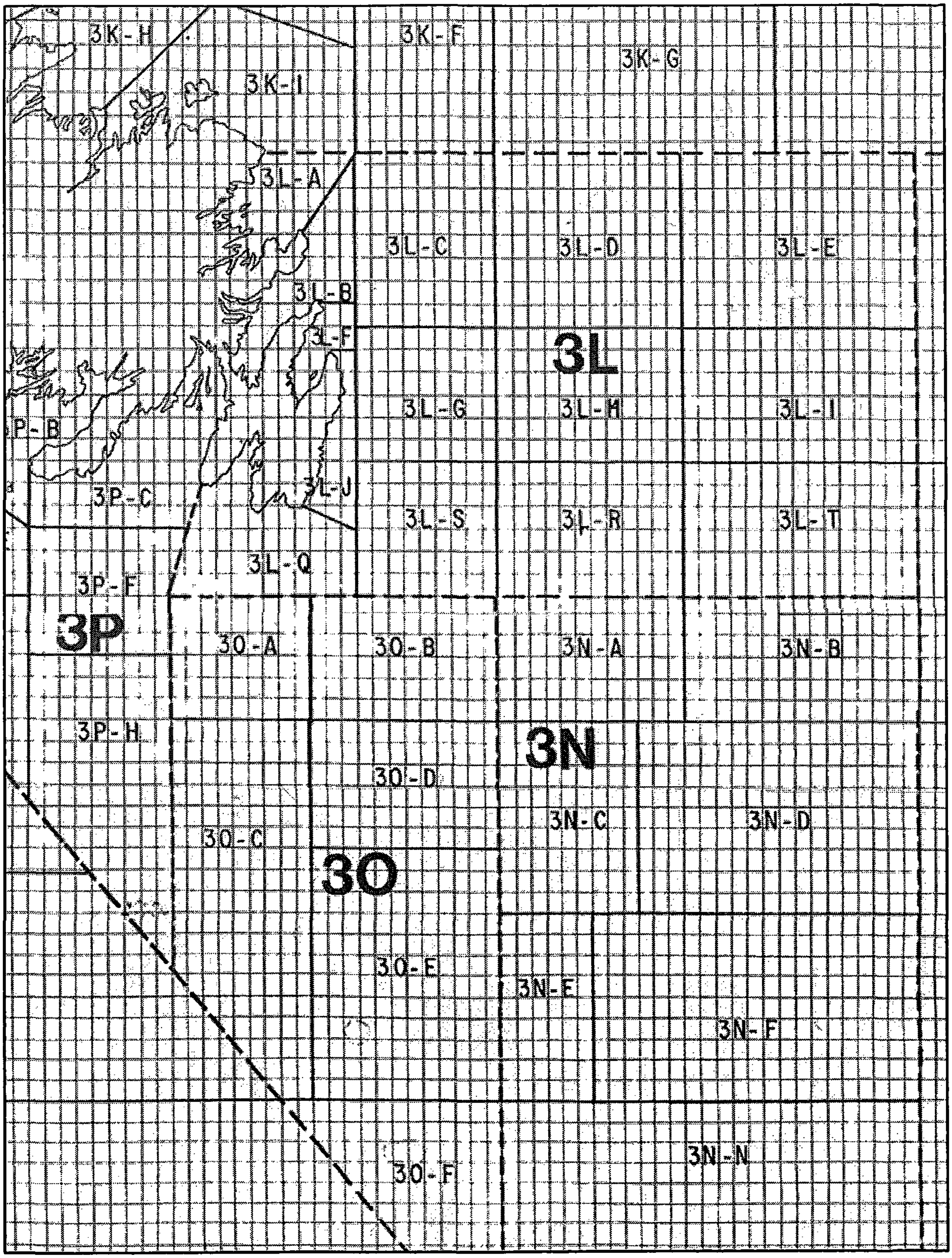

Figure A.12.2 NAFO Subdivisions (DFO)

Appendix B Model Input

This appendix presents an example of model input, in this case the separable model "capelin". The information given in this example is representative of the 153 models run and analyzed. Three separate screen captures are shown, two of which correspond to the data input and the third to the model itself as solved by What'sBest!

1. Figure B.1

The inputs shown on Figure B.1 are used in the "Model" analysis (See section 5.3). Following inputs for each area and time period (week) combination:

- Landed price per kg of fish
- Average catch per vessel
- Objective function coefficients
- Average catches for all vessels, with overall totals by area and by time period
- Average number of vessels, with totals by area and time period.

2. Figure B.2

It contains the same inputs as Figure B.2, with the addition of operating cost data. The following items are added:

- Vessel activity
- Objective function coefficients with operating costs
- Operating cost components

3. Figure B.3

The final figure in this appendix shows the structure of the model as solved with What'sBest! (WB!).

- The first three rows contain the location, week and corresponding decision variable (number of vessels).
- The next two rows contain the objective function coefficients and the average catch per vessel.

- On the top left is the objective function value, which WB! seeks to maximize while meeting the constraints.
- The next blocks of row are the constraints; first the catch constraints by location and time period, then the fleet size constraints, also by location and time period.

Landed price										
per kg	26	27	28	29	30	31	32			
3La	$0.00	$0.25	$0.25	$0.18	$0.13	$0.13	$0.12			
3Lb	$0.20	$0.21	$0.21	$0.18	$0.13	$0.14	$0.24			
3Lf	$0.29	$0.29	$0.22	$0.18	$0.17	$0.14	$0.00			
Average catch										
per Vessel	26	27	28	29	30	31	32			
3La	0	38,901	52,292	43,481	40,133	80,513	27,158			
3Lb	17,191	59,288	32,568	37,581	41,301	12,803	6,849			
3Lf	24,798	53,537	64,029	53,974	41,577	78,930	0			
Obj Fcn Coeff	26	27	28	29	30	31	32			
3La	0	9,806	12,893	7,953	5,258	10,342	3,132			
3Lb	3,466	12,670	6,729	6,796	5,247	1,854	1,674			
3Lf	7,107	15,265	13,884	9,950	6,948	10,901	0			
									Total by Period	
Average Catches									62984	26
for all Vessels	26	27	28	29	30	31	32	Total by Area	1,939,116	27
3La	0	324,172	1,071,987	1,210,223	354,509	415,981	31,684	3,408,555	4,505,046	28
3Lb	25786	918,965	1,384,135	1,991,789	1,039,397	110,962	14,839	5,485,872	4,074,592	29
3Lf	37198	695,980	2,048,925	872,579	263,318	92,085	0	4,010,086	1,657,225	30
Total by Period	62984	1,939,116	4,505,046	4,074,592	1,657,225	619,029	46,522	12,904,513	619,029	31
									46,522	32
									Vessels by Period	
Ave Number of vessels	26	27	28	29	30	31	32	Total by Area	3.0	26
3La	0.0	8.3	20.5	27.8	8.8	5.2	1.2	71.8	36.8	27
3Lb	1.5	15.5	42.5	53.0	25.2	8.7	2.2	148.5	95.0	28
3Lf	1.5	13.0	32.0	16.2	6.3	1.2	0.0	70.2	97.0	29
Total by Period	3.0	36.8	95.0	97.0	40.3	15.0	3.3	290.5	40.3	30
									15.0	31
									3.3	32

Figure B.1 Capelin Model Data Input

Landed price										
per kg	26	27	28	29	30	31	32			
3La	$0.00	$0.25	$0.25	$0.18	$0.13	$0.13	$0.12			
3Lb	$0.20	$0.21	$0.21	$0.18	$0.13	$0.14	$0.24			
3Lf	$0.29	$0.29	$0.22	$0.18	$0.17	$0.14	$0.00			
Average catch										
per Vessel	26	27	28	29	30	31	32			
3La	0	38,901	52,292	43,481	40,133	80,513	27,158			
3Lb	17,191	59,288	32,568	37,581	41,301	12,803	6,849			
3Lf	24,798	53,537	64,029	53,974	41,577	78,930	0			
Obj Fcn Coeff	26	27	28	29	30	31	32			
3La	0	9,806	12,893	7,953	5,258	10,342	3,132			
3Lb	3,466	12,670	6,729	6,796	5,247	1,854	1,674			
3Lf	7,107	15,265	13,884	9,950	6,948	10,901	0			
									Total by Period	
Average Catches									62984	26
for all Vessels	26	27	28	29	30	31	32	Total by Area	1,939,116	27
3La	0	324,172	1,071,987	1,210,223	354,509	415,981	31,684	3,408,555	4,505,046	28
3Lb	25786	918,965	1,384,135	1,991,789	1,039,397	110,962	14,839	5,485,872	4,074,592	29
3Lf	37198	695,980	2,048,925	872,579	263,318	92,085	0	4,010,086	1,657,225	30
Total by Period	62984	1,939,116	4,505,046	4,074,592	1,657,225	619,029	46,522	12,904,513	619,029	31
									46,522	32
									Vessels by Period	
Ave Number of vessels	26	27	28	29	30	31	32	Total by Area	3.0	26
3La	0.0	8.3	20.5	27.8	8.8	5.2	1.2	71.8	36.8	27
3Lb	1.5	15.5	42.5	53.0	25.2	8.7	2.2	148.5	95.0	28
3Lf	1.5	13.0	32.0	16.2	6.3	1.2	0.0	70.2	97.0	29
Total by Period	3.0	36.8	95.0	97.0	40.3	15.0	3.3	290.5	40.3	30
									15.0	31
Activity									3.3	32
#Days wk avg	26	27	28	29	30	31	32			
3La	0.00	2.97	3.65	3.20	3.03	5.08	2.38			
3Lb	1.87	4.00	2.65	2.90	3.09	1.65	1.35			
3Lf	2.26	3.71	4.24	3.74	3.11	5.00	0.00			
Obj Coeff with cost	0	6241	8513	4109	1617	4245	280			
	1221	7864	3548	3310	1535	-125	58			
	4399	10809	8790	5467	3220	4901	0			
Daily Operating Costs										
Labour	884.68	0.74								
Fuel	116.60	0.10								
Other	198.72	0.17								
Total	1200.00	0.47	Cost to Revenue Ratio							

Figure B.2 Capelin Model with Operating Costs – Data Input

	Location	3La	3La	3La	3La	3La	3La	3La	3Lb	3Lb	3Lb	3Lb	3Lb	3Lb	3Lb	3Lf	3Lf	3Lf	3Lf	3Lf	3Lf	3Lf			
	Week	26	27	28	29	30	31	32	26	27	28	29	30	31	32	26	27	28	29	30	31	32			
Obj Fcn Value	Number of vessels	0.0	0.0	65.2	0.0	0.0	0.0	0.0	1.5	0.0	25.8	76.1	40.1	1.6	3.3	1.5	36.2	4.0	20.9	0.0	7.6	0.0			
$2,665,087	Obj Fcn Coeff	0	9,806	12,893	7,953	5,258	10,342	3,132	3,466	12,670	6,729	6,796	5,247	1,854	1,674	7,107	15,265	13,884	9,950	6,942	10,901	0			
	Ave Weekly Catch per Vessel	0	18,901	52,292	43,481	40,533	80,513	27,156	17,191	59,288	32,568	37,581	41,301	12,803	6,849	24,798	53,537	64,029	53,974	41,577	78,930	0			
Constraints																									Constraints
Max Catch per Period	26	1							1							1							52,984	≤	52,964
	27		1							1							1						1,939,116	≤	1,939,116
	28			1							1							1					4,505,046	≤	4,505,046
	29				1							1							1				3,987,545	≤	4,074,592
	30					1							1							1			1,657,225	≤	1,657,225
	31						1							1							1		619,029	≤	619,029
	32							1							1							1	22,828	≤	46,522
Max Catch by Area	3La	1	1	1	1	1	1	1															3,408,555	≤	3,408,555
	3Lb								1	1	1	1	1	1	1								5,428,243	≤	5,485,5[illegible]
	3Lf															1	1	1	1	1	1	1	3,956,974	≤	4,0[illegible]
Upper Bound on Fleet Size by Period	26	1							1							1							3.0	≤	3.0
	27		1							1							1						36.2	≤	76.8
	28			1							1							1					95.0	≤	[illegible]
	29				1							1							1				97.0	≤	[illegible]
	30					1							1							1			40.1	≤	40.1
	31						1							1							1		9.2	≤	15.0
	32							1							1							1	3.3	≤	3.3
Upper Bound on Fleet Size by Area	3La	1	1	1	1	1	1	1															65.2	≤	71.8
	3Lb								1	1	1	1	1	1	1								148.5	≤	149.5
	3Lf															1	1	1	1	1	1	1	70.2	≤	70.2

Figure B.3 Capelin Model

Appendix C Model Outputs

The screenshots presented in this appendix correspond to the capelin model output and are representative of the 153 separable models run and analyzed.

1. Figure C.1What'sBest! (WB!) Status Report. This report gives the user information regarding the model and the solution, including:
    - Number of variables
    - Number of constraints
    - Model type (linear in this case)
    - Objective function value
    - Solution time
2. Figure C.2 WB! Solution Report contains sensitivity analysis information:
    - Adjustable cells (decision variables) values and their reduced cost. The reduced cost is the penalty imposed on the objective function value as a result of introducing a decision variable with an optimal value of zero into the solution.
    - Constraint dual values. The dual value is the rate of improvement in the objective function value as the constraint is increased.

```
What'sBest!® 9.0.3.6 (Feb 11, 2009) - Library 5.0.1.363 - Status Report -

DATE GENERATED:            Apr 20, 2009                 11:23 AM


MODEL INFORMATION:

  CLASSIFICATION DATA           Current   Capacity Limits
  --------------------------------------------------------
  Numerics                        810
  Variables                        62
  Adjustables                      21                8000
  Constraints                      20                4000
  Integers/Binaries               0/0                 800
  Nonlinears                        0                 800
  Coefficients                    160

  Minimum coefficient value:      1  on Model!A6
  Minimum coefficient in formula:   Model!A6
  Maximum coefficient value:      5485872.3333333  on <RHS>
  Maximum coefficient in formula:   Model!Y19

MODEL TYPE:              Linear

SOLUTION STATUS:         GLOBALLY OPTIMAL

OBJECTIVE VALUE:         2665086.7528135

DIRECTION:               Maximize

SOLVER TYPE:             . . .

TRIES:                   20

INFEASIBILITY:           9.31322574615448e-010

BEST OBJECTIVE BOUND:    . . .

STEPS:                   . . .

ACTIVE:                  . . .

SOLUTION TIME:           0 Hours  0 Minutes  0 Seconds

NON-DEFAULT SETTINGS:

  General Options / Solution Report:   Always Created

End of Report
```

Figure C.1 Capelin Model – WB! Status Report

What'sBest!® 9.0.3.6 (Feb 11, 2009) - Library 5.0.1.363 - Solution Report -

DATE GENERATED: Apr 20, 2009 11:23 AM

OBJECTIVE CELL	VALUE	INITIAL VALUE	TYPE	DECREASE	INCREASE
Model!A6	2.665087e+006	0.000000e+000	MAXIMIZE		

ADJUSTABLE CELLS	VALUE	INITIAL VALUE	TYPE	REDUCED COST	DECREASE	INCREASE
Model!C4	0.000000e+000	0.000000e+000	C	1.652694e+003	6.637915e-001	4.601586e-001
Model!D4	0.000000e+000	0.000000e+000	C	1.725195e+003	6.547487e+000	2.242883e+000
Model!E4	6.518308e+001	0.000000e+000	C	0.000000e+000	+Infinity	6.518308e+001
Model!F4	0.000000e+000	0.000000e+000	C	1.761699e+003	7.647058e+000	1.199575e+001
Model!G4	0.000000e+000	0.000000e+000	C	2.500332e+003	5.196238e+000	7.335764e+000
Model!H4	0.000000e+000	0.000000e+000	C	3.558403e+003	4.011459e+000	2.554814e+000
Model!I4	0.000000e+000	0.000000e+000	C	9.773629e+001	2.761338e+000	1.166667e+000
Model!J4	1.500000e+000	0.000000e+000	C	0.000000e+000	+Infinity	1.500000e+000
Model!K4	0.000000e+000	0.000000e+000	C	6.657459e+002	5.708066e+000	3.110041e+000
Model!L4	2.583049e+001	0.000000e+000	C	9.094947e-013	+Infinity	2.583049e+001
Model!M4	7.612563e+001	0.000000e+000	C	0.000000e+000	+Infinity	7.612563e+001
Model!N4	4.012598e+001	0.000000e+000	C	9.094947e-013	+Infinity	4.012598e+001
Model!O4	1.584576e+000	0.000000e+000	C	0.000000e+000	+Infinity	1.584576e+000
Model!P4	3.333333e+000	0.000000e+000	C	0.000000e+000	+Infinity	3.333333e+000
Model!Q4	1.500000e+000	0.000000e+000	C	0.000000e+000	+Infinity	1.500000e+000
Model!R4	3.622016e+001	0.000000e+000	C	1.818989e-012	+Infinity	3.622016e+001
Model!S4	3.986432e+000	0.000000e+000	C	0.000000e+000	+Infinity	3.986432e+000
Model!T4	2.087437e+001	0.000000e+000	C	4.547474e-013	+Infinity	2.087437e+001
Model!U4	0.000000e+000	0.000000e+000	C	1.482904e+003	4.272927e+000	2.098342e+001
Model!V4	7.585704e+000	0.000000e+000	C	4.547474e-013	+Infinity	7.585704e+000
Model!W4	0.000000e+000	0.000000e+000	C	4.827997e+003	9.840146e-001	1.875196e+000

B: Binary, C: Continuous, F: Free, I: Integer

CONSTRAINT CELLS	DUAL VALUE	SLACKS	TYPE	DECREASE	INCREASE
Model!Y10	6.401987e-002	0.000000e+000	<=	1.141117e+004	1.141117e+004
Model!Y11	2.129076e-001	0.000000e+000	<=	2.381663e+005	3.282764e+004
Model!Y12	1.271799e-001	0.000000e+000	<=	1.254173e+005	1.661805e+005
Model!Y13	-0.000000e+000	8.704657e+004	<=	8.704657e+004	+Infinity
Model!Y14	1.057867e-001	0.000000e+000	<=	2.407706e+005	8.563802e+003
Model!Y15	8.911692e-002	0.000000e+000	<=	3.511314e+005	1.047830e+005
Model!Y16	-0.000000e+000	2.369387e+004	<=	2.369387e+004	+Infinity
Model!Y18	8.352798e-002	0.000000e+000	<=	6.941980e+004	3.048479e+005
Model!Y19	-0.000000e+000	5.762926e+004	<=	5.762926e+004	+Infinity
Model!Y20	-0.000000e+000	5.311118e+004	<=	5.311118e+004	+Infinity
Model!Y24	1.652694e+003	0.000000e+000	<=	4.601586e-001	6.637915e-001
Model!Y25	-0.000000e+000	6.131774e-001	<=	6.131774e-001	+Infinity
Model!Y26	1.874333e+003	0.000000e+000	<=	5.829720e+000	1.327541e+000
Model!Y27	6.083065e+003	0.000000e+000	<=	5.829720e+000	1.327541e+000
Model!Y28	-0.000000e+000	2.073533e-001	<=	2.073533e-001	+Infinity
Model!Y29	-0.000000e+000	5.829720e+000	<=	5.829720e+000	+Infinity
Model!Y30	9.613521e+002	0.000000e+000	<=	3.333333e+000	1.327541e+000
Model!Y32	-0.000000e+000	6.650251e+000	<=	6.650251e+000	+Infinity
Model!Y33	7.127425e+002	0.000000e+000	<=	1.327541e+000	5.829720e+000
Model!Y34	3.866644e+003	0.000000e+000	<=	1.327541e+000	1.080769e+000

Figure C.2 WB! Solution Report