Penguins And Krill - Life in a Changing Ocean

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Abstract
Populations of Adélie and chinstrap penguin in the West Antarctic Peninsula/Scotia Sea have declined more than 50% during the last 30 years. Changes in the abundance of their main prey - Antarctic krill - as a result of climate-driven changes could be the cause of this reduction of penguin populations. As the extent of the impact of climate change on krill populations remains uncertain, the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR; www.ccamlr.org) should keep a precautionary approach in the management of the krill fishery to secure the protection of penguins. This paper provides an overview of current challenges in the management of the Antarctic krill fishery so as to maintain krill availability to penguins in key areas.

Keywords
Antarctic krill fisheries; Penguin population declines; Commission for the Conservation of Antarctic Marine Living Resources; Antarctica; feedback management; climate change

1. Introduction
The Commission for the Conservation of Antarctic Marine Living Resources ("CCAMLR") is generally regarded as a model for regional cooperation in the area of fisheries, implementing laws for the management of marine resources based on conservation principles. One of the central and continuing tasks of CCAMLR is the ecosystem management of the Antarctic krill fishery.

„Krill" is a term applied to describe over 80 species of open-ocean crustaceans known as Euphausiids. Euphausia superba is the species commonly referred to as "Antarctic krill," which are shrimp-like crustaceans. Adult krill aggregate into huge schools or swarms, that may extend for kilometers with thousands of krill packed into each cubic meter. This swarming behavior is what makes krill attractive to commercial harvesting

Antarctic krill are central to the Antarctic marine food web, as most organisms are either direct predators of krill or are just one trophic level removed from it. For many marine mammals and sea birds (especially penguins), krill is the most abundant food source. Areas of highest krill concentration are often close to the land-based breeding colonies of krill-eating seabirds and seals. These predators depend on krill being within reach of their colonies in order to feed and rear their offspring during the Antarctic summer.
Interest in krill fisheries began in the 1960s, with the highest catches occurring in the early 1980s, reaching over half a million tons. In the early nineties, catches dropped dramatically due to the break-up of the Soviet Union, which forced this heavily subsidized fleet to cease operations. Catches of Antarctic krill have increased substantially in recent years, re-

aching a maximum of 282,000 tons in the 2013/2014 fishing season, and concentrating repetitively in certain areas over and over. The Antarctic krill fishery may become the largest global fishery, with the potential to affect significantly the trophic structure of the Antarctic marine ecosystem.

This paper describes current challenges in the management of Antarctic krill fisheries in the context of declining penguin populations, resulting most likely as a result of climate-driven changes.

2. Penguins, climate change and the Antarctic krill fishery

The reduction of the populations of Adélie and chinstrap penguin in the West Antarctic Peninsula/Scotia Sea area[1] requires that the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) continues to advance in the management of the krill fishery. New and alarming evidence has been published in recent years about the reduction of the populations of Adélie (*Pygoscelis adeliae*) and chinstrap penguins (*Pygoscelis antarctica*) in the West Antarctic Peninsula/Scotia Sea area. Populations of these species have declined more than 50% during the last 30 years at study colonies in the South Shetland Islands, which is consistent with the trend observed in the population of both species throughout the Scotia Sea [2]. Significant declines in the breeding population of chinstrap penguins in Deception Island's largest chinstrap colony known as Baily Head have been confirmed recently by researchers from the Antarctic Site Inventory [2]. Changes in the abundance of Antarctic krill (the main prey of both species) could be the cause of the reduction of penguin populations. Previous studies indicate that as a result of climate-driven changes, particularly sea-ice reduction, abundance of krill in this area may have reduced by as much as 80% from existing population levels in the 1970s [3].

CCAMLR have been applying a precautionary approach in the management of the krill fishery [4][5]. In the context of the observed reduction of penguin populations in the West Antarctic Peninsula/Scotia Sea, and as the extent of the impact of climate change on krill populations remains uncertain, it is fundamental that krill fisheries management is conducted so as to maintain krill availability to penguins in key areas. This is of particular importance since there is still insufficient knowledge about the impacts of the fishery on krill populations and krill dependent predators.

The breeding distribution of penguins and the foraging range during breeding (when they behave as central place foragers) is an important element in any consideration related to krill fisheries management. Current krill fisheries are operating close to shore in areas where penguins forage. Thus, krill fishing has the potential to have significant localized impact on krill availability in penguin foraging areas, especially during the breeding season. As knowledge of whether or not

1 This is the region where the krill fishery currently operates.

Chinstrap penguins (*Pygoscelis antarctica*) (Photo: R. Werner)

Adélie penguin (*Pygoscelis adeliae*) (Photo: R. Werner)

Gentoo penguins (*Pygoscelis papua*) (Photo: R. Werner) krill live in local stationary populations or migrate over larger areas using the ocean currents is incomplete, it is important that a precautionary approach be taken regarding fishing activities in these important foraging areas.

Key penguin species for which data exist in the Antarctic Peninsula/Scotia Sea are Chinstrap, Adélie and Gentoo. Historically, fishing has been taking place during the summer when penguins are constrained on where and how far they can travel to forage, resulting in an overlap between fishing operations and the foraging range of penguins. The level of overlap will depend, amongst others, on the species being considered as well as the specific location and time period. Nevertheless, in recent years, the fishery is changing its temporal scale and becoming more of a winter fishery. Also, fishing is concentrating on particular sites not necessarily in line with historical fishing patterns. The potential impact of fishing becomes more concerning since for the last 15 years krill fishing activity in FAO Statistical Area 48 has been approximately occurring in only a quarter of the area open to krill fishing and has been occurring in a concentrated way. Specifically, current krill fishing takes place in Subareas 48.1 (Antarctic Peninsula), 48.1 (South Orkneys) and Subarea 48.3 (South Georgia). Catch limits for krill apply also to Subarea 48.4 although no fishing has taken place in this subarea in recent years.

Most existing data on penguin foraging is from the summer, the peak of the breeding season for penguin species resident to the Antarctic Peninsula /Scotia Sea. Winter feeding grounds for penguin species in this area are still unknown. Some species will distribute along the ice edge, moving northward as the winter progress (e.g., chinstrap penguins) but satellite tagging data will be needed to validate this and determine winter feeding grounds for all penguin species. Information on penguin foraging in winter is crucial so as to determine the level of overlap between the krill fishery and penguins over time since krill distribution and abundance changes also seasonally and interannually.

3. Important element to secure the protection of penguins

3.1 Feedback management

Feedback management requires monitoring to allow management to be adjusted as relevant information becomes available. Having embraced the precautionary approach in managing fisheries, CCAMLR needs to adjust fishing activities (i.e. krill catch, and its geographical and temporal distribution) in response to the changes of monitored indicators. In 2010, CCAMLR's Scientific Committee (SC-CCAMLR) recognized that the management of the krill fishery was facing important challenges that still needed to be resolved. Consequently, the work on krill was prioritized with a special focus on the development of feedback management, amongst others.

Recent developments with regards to a feedback management strategy for the krill fishery are encouraging. CCAMLR has considered initial elements that include the development of a list of candidate feedback management approaches and the identification of an agreed suite of indicators. This is of particular importance in Antarctica since in a changing ecosystem such as the Southern Ocean the only adjustment that CCAMLR can exert is through managing fisheries.

Although candidate feedback approaches that are currently being discussed may be feasible to be implemented in the near future, in the meantime it would be important to take increased precaution in the distribution of local catch limits, especially taking into account the uncertainties related to the impact of climate change and to the estimation of krill total removals by the fishery.

3.2 The need to revise and expand CEMP

Monitoring is central to feedback management and therefore, it is critical to have an effective CCAMLR Ecosystem and Monitoring Program (CEMP). CEMP was designed to monitor the effects of the krill fishery on krill predators as opposed to those produced by environmental changes. Currently, monitoring data, which includes predator, environmental and prey (krill) parameters, are being gathered from a network of determined sites (CEMP sites) in relation to a limited number of krill-dependent predators in land-based colonies which were selected as indicator species[2].

The sites monitored and the data submitted to CEMP have been decreasing in recent years. In addition, climate change could potentially induce rapid changes within the ecosystem, impacting the way indices generated by CEMP are being used to detect fisheries impacts. As already recognized by CCAMLR, in its current configuration CEMP does not allow distinguishing the impacts of fishing from those associated with environmental change, its main objective at the time of its creation. Consequently, a review of CEMP, including the requirements for its monitoring reference sites is urgently needed.

The implementation of feedback management in Area 48 based on the current monitoring of CEMP would require a highly precautionary approach with regards to krill catches and/or to spatially restrict catches, focusing only in those areas where existing monitoring occurs. To distinguish between climate change and fisheries impacts, it may be necessary to establish reference (control, i.e. complementary no fishing) sites and/or additional parameters. A spatial subdivision of the fishery could be a valuable approach for

2 A list of monitored parameters was developed for CEMP, which includes predator, environmental and prey (krill) parameters. Fieldwork and data acquisition for predator parameters (indicator species) are voluntarily carried out by CCAMLR Member countries and submitted to the CCAMLR Secretariat. The Secretariat uses fisheries data submitted by Members to calculate some of the krill-related parameters. Furthermore, some environmental parameters, such as sea ice cover or sea surface temperatures are derived from publicly available datasets.

Lemaire Channel, a strait off Antarctica, between Kiev Peninsula and Booth Island (Photo: R. Werner)

the development of feedback management procedures in the krill fishery. Following this, some areas could be closed to fishing (control or reference areas), whereas in other areas, with similar ecological features, fishing could be allowed, setting area-specific catch limits. Comparison between no-take areas and fishing areas could help to assess the effects of fishing. Also, CCAMLR should take advantage of all existing monitoring opportunities, including selected land-based monitoring sites, fishing and research vessels to collect data.

An expansion of CEMP will necessarily include the establishment of new monitoring sites in areas known to be fished so as to obtain the required baseline monitoring information. Collecting baseline information on land-based predators is time consuming, and thus it would be important to ensure the continuity of current monitoring sites that have been creating relevant time data series.

Current CEMP sites are the result of national research programs [3] of member countries and are not necessarily established with the intention of providing data for feedback management purposes. In addition, there are other areas in the Antarctic Peninsula/Scotia Sea where research programs to monitor land-based predators are being conducted by Parties to the Antarctic Treaty and CCAMLR, and by other research bodies. Although information arising from these projects could represent potentially an important contribution to CEMP, currently no data are being provided. It becomes relevant therefore to coordinate monitoring activities with the Committee on Environmental Protection (CEP) of the Antarctic Treaty Consultative Meeting (ATCM). Of particular importance would be that CCAMLR establishes some cooperation with the Council of Managers of National Antarctic Programs (COMNAP) so as to identify projects that could provide data to help expand the spatial extent of CEMP, which would facilitate the development of a feedback management system.

In the case of penguins, in addition to sites that are systematically being monitored, it would be important to conduct surveys to reduce uncertainty in estimates of penguin abundance, and subsequently estimates of krill consumption by penguins, in other penguin colonies.

In recent years, it has become clear that to increase availability of data on predator abundance throughout Area 48, CCAMLR could combine the use of satellite remote-sensing aerial surveys, visits to penguin breeding colonies using ships of opportunity, and remote cameras to provide broad-scale information on the size and trends of regional predator populations. To make progress in these areas, it is recommended that CCAMLR engages IAATO members (International Association of Antarctic Tourist Operators) in supporting monitoring of penguin colonies visited by tourists during the penguin breeding season (i.e. by sponsoring equipment, facilitating logistics, etc.).

With regards to the understanding of foraging distribution of land based predators in general, tracking instruments have been deployed only at a restricted number of breeding sites, thus substantial work is needed with regards to making

3 National Antarctic Programs are those organizations that have responsibility for delivering and supporting scientific research in the Antarctic Treaty Area.

predictions for colonies where no tracking data exist, or colonies where tracking data are only available for certain times of the year. The data gathered so far indicate that some species have restricted movements while others travel long distances, and that foraging movements may vary substantially across seasons and between life-history stages. This type of information will be key for the implementation of feedback management, and especially, for the establishment of MPAs in Area 48.

3.3 General considerations in the establishment of marine protected areas (MPAs) in the context of the krill fishery

Besides of adopting spatial area limitations to protect important penguin foraging areas, CCAMLR would need to establish some reference areas in the development of a feedback management strategy for the krill fishery. In the case of existing study locations, such as CEMP sites, it would be important to determine which sites could be included in potential MPAs to be protected from the impact of the fishery and which sites should remained exposed to fishing operations to register any potential impact from the krill fishery. Other locations (sites) that are not part of CEMP but are currently being monitored by Members should also be considered for protection when designing MPAs in the context of a feedback management strategy. Also areas that have been historically not fished as opposed to other areas that were heavily fished over the years will need to be considered in the analysis. Finally, Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs) established by the ATCM, which are important for their own reasons, should be given full protection from the fishery.

4. Remaining challenges in the management of the krill fishery

4.1 The Trigger Level and climate change

The life history and demography of Antarctic krill are intimately tied to seasonal sea ice conditions, climate, and the physical forcing of ocean currents. Key spawning, recruitment and nursery areas of krill are located in the Southwest Atlantic sector (West of the Antarctic Peninsula). The climate in this area is warming rapidly, and as a result, the extent and duration of winter sea ice has declined. The reproduction and survival of krill are significantly affected by sea ice cover [6] and it has been shown that summer krill densities correlate to both the duration and the extent of sea ice during the previous winter [3]. Accordingly, krill biomass seems to have been reduced in this area for at least the period from 1976 to 2003 [3].

Climate change impacts on the Antarctic ecosystems are of major concern, and thus, management decisions would need to consider how climate change affects the marine ecosystem. This is of particular importance, since climate change, combined with changes in oceanography, has the potential to induce rapid change within ecosystems, resulting in important implications for the management of the Antarctic krill fishery.

In April 2011, the workshop on "Antarctic Krill and Climate Change" that took place in Texel, Netherlands, discussed krill biology in the context of climate change and the potential implications for krill fisheries management. Participants reviewed trends in the effects of climate change, such as ocean warming, sea-ice decline and ocean acidification, and the potential implications for krill stocks. The workshop noted that environmental changes will act in concert to modify the abundance, distribution and life cycle of krill. In addition, it was concluded that the impact of climate change is predicted to increase considerably in the Southern Ocean over the next few decades, and that the resulting changes will likely impact negatively on krill [7].

Workshop participants considered recruitment, driven by the winter survival of larval and juvenile krill, to be the most susceptible to climate change amongst the population parameters determining the distribution and biomass of krill. The workshop also concluded that it seems inappropriate to consider stable recruitment of krill in the context of the impacts of climate change, especially in the Antarctic Peninsula and Scotia Sea area. It was concluded that while CCAMLR further investigates this particular aspect, precaution should be implemented in the light of an increasing krill fishery [7].

The „trigger level" (620,000 tonnes) currently operates as the maximum allowable krill catch in Area 48 and was established on the basis of summing the maximum historical krill catch in each subarea, which amounts to 619,500 tonnes (for more information on the trigger level see [5]).

Related impacts from climate change have increased significantly since 1991 (when the trigger level was introduced). Thus, the conditions under which the trigger level was introduced have changed and it is no longer valid to rely on the original catches on which the trigger level was established.
Clearly, if monitoring data were to indicate that predators were decreasing in Area 48, possibly because of ecosystem changes related to climate change, CCAMLR would need to modify the distribution and intensity of fishing. For example, is the drop in population numbers of chinstrap and Adélie in the Antarctic Peninsula/Scotia Sea already a good indicator that should trigger a change in the distribution and intensity of fishing in this area? This question highlights the need to undertake a good quantitative study of the factors that might be inducing a drop in penguin numbers, including an analysis on the effect of fishing on these declines.

It is important to take into account the uncertainties related to the impact of climate change on the abundance of krill in important penguin foraging areas. In recent years, the krill fishery has concentrated heavily in coastal areas. In 2009/2010 catches were concentrated in the Bransfield Strait (in Subarea 48.1) with 80 % of the total catch in Subarea 48.1 occurring mainly in two Small Scale Management Units (SSMUs)[4]. In addition, catches that year were 20 times greater than the average historical catch in these SSMUs. Fishing in the 2012/2013 and 2013/2014 concentrated again in the Bransfield Strait, leading to the closing of Subarea 48.1 when the catch limit was reached during both fishing seasons. This is the third time since the establishment of CM 51-07 that the Subarea was closed before the end of the fishing season after reaching the catch limit in this area. In addition, total catches in the 2013/2014 season (data available until September 2014) have reached an historical maximum of 282,000 tonnes which is almost three times the catches in the year 2000. This highlights the need for CCAMLR to adopt additional measures to prevent excessive concentration of krill catches in coastal areas (potentially leading to a localized depletion of krill availability).

4.2 Old data and the need for a new CCAMLR Synoptic Survey
CCAMLR has already recognized that there is a lack of up-to-date information on the spatial distributions and trends in krill biomass, fishable biomass and the magnitude of the krill movement throughout Area 48. Estimates of pre-exploitation biomass of krill (B0) are uncertain for a variety of reasons. Of greatest concern is the fact that the last krill synoptic survey for Area 48 conducted by CCAMLR members occurred in 2000. Moreover, it is now understood that krill are increasingly impacted by climate change. Therefore, CCAMLR Members should take the necessary steps to conduct a new krill synoptic survey to obtain a new biomass estimate for Area 48. Besides of krill biomass information at the basin scale, a synoptic survey could help in foreseen effects from climate change, sea ice reduction, fishing operations, ocean acidification, etc. for areas that might not be covered by regional surveys. Similar conclusions have been reached at a recent cross-sector workshop on krill fishing and conservation in the Scotia Sea and Antarctic Peninsula region [8]. In addition, one of the key findings of this workshop is the need to formulate a research and development strategy to support progress in the management of the Antarctic krill fishery so that the limited available resources can be targeted appropriately. This strategy should allow the identification of priority objectives for research and development in support of CCAMLR's management of the krill fishery.

To complement the results from a krill synoptic survey, new cost effective methods being developed could provide information on krill biomass and distribution in Area 48 in a timely manner. Besides data provided by krill fishing vessels, it would be important to dedicate research cruises in areas outside historical fishing ground to provide a comprehensive coverage of Area 48. The appropriate assessment of krill biomass and distribution would be key for the implementation of the feedback management in Area 48.

4.3 The need to estimate total krill removals
CCAMLR set catch limits for its fisheries at a level that is considered sustainable. This is conducted under the assumption that the reported catch from a fishery reflects the total removals by that fishery from the exploited population. In the krill fishery there are still some problems related to estimating total removals of the krill based on the uncertainties associated to estimating the green weight and the krill escapement mortality.

4.4 Green weight
Green weight is defined as the total weight of krill landed on the vessel, which is assumed to be equivalent to total removals.

CCAMLR has yet to adopt a standardized reporting method for krill catches. As was noted by the SC-CCAMLR in 2011, all methods for estimating green weight of krill have associated uncertainty, and the absolute uncertainty in catch estimates increases in proportion to the catch [9]. This uncertainty is not accounted for in the current management process for krill and does not only affects assessments of krill stocks, but also the estimations of the impact of krill removals on predators. Moreover, it raises important enforcement issues.

Currently, CCAMLR Members are required to report green weight and the method used to estimate it. Nevertheless, the level of accuracy in estimated green weight continues to differ between methods and seasons. In addition, the methods used to estimate green weight by different Members have a variable uncertainty that is still not accounted for.

4.5 Krill escape mortality
Krill escape mortality occurs when krill gets squeezed through the nets while fishing, an unknown percentage of which gets killed or seriously injured, without being counted as caught. In practical terms, krill escape mortality is calculated as the amount of krill escaping through the trawl mesh multiplied by the proportion of animals that die as a result of this process.

The issue of krill escape mortality from krill nets raises further concerns about the capacity to effectively measure krill removals during fishing operations. Many different factors such as krill density, type of gear, speed of trawling, and mesh size are likely to affect escape mortality. Krill trawl net escapement mortality represents an important source of uncertainty, which further undermines CCAMLR's capacity to determine the real impact of fishing operations on the ecosystem. Although some initial experiments have been conducted during the last couple of years, there are no conclusive estimates on the level of krill escape mortality. The further

4 In 2002, the Commission subdivided the South West Atlantic into fifteen small units for the management of the krill fishery known as Small-Scale Management Units or SSMUs.

investigation on krill escape mortality is fundamental for the assessment of total krill removals by fishing operations.

4.6 Scientific observer coverage

Over many years, the Scientific Committee has recommended 100% scientific observation across all vessels in the krill fishery as the best way to achieve systematic observer coverage, meaning a level of coverage that ensures data collection across all areas, seasons, vessels and fishing methods. A robust scientific observation program is necessary to understand the overall behavior and impact of the fishery and is also fundamental to collect biological data—a factor that currently limits CCAMLR's ability to monitor and manage the krill fishery.

For many years, the Scientific Committee has been advising on the need to have deployment of 100% scientific observer coverage on board krill vessels. Clearly the reasons that have been impeding this observer scheme are political and not scientific. For example, back in 2007, Members of CCAMLR's Working Group on Ecosystem Monitoring and Management (WG-EMM) expressed already their frustration that the collection of scientific observer data, which was granted a high priority by the Scientific Committee, was being impeded by non-scientific arguments [10].

At CCAMLR XXVIII- 2009 CCAMLR adopted CM 51-06 that made mandatory the deployment of scientific observers on board krill vessels. This CM resulted in 30% mandatory observer coverage in the first year, and 50% in the second year. This represented a key step forward in the establishment of a comprehensive scientific observation program.

At the recent meeting of WG-EMM in July 2014, the need to improve data quality, including securing the training of scientific observers, was discussed. Also, the Working Group agreed that scientific observers could provide guidance in assisting the crew to estimate the green weight of krill caught, highlighting the need for 100 % krill fishing observers in this context. Furthermore, some krill fishing operators are concerned that transshipment operations are not necessarily covered by observers due to the current level of coverage, allowing for catch underreporting. Thus, a 100% observer coverage is not only recommended to improve the availability of krill fishing data to WG-EMM, but also to secure, full observation coverage during transshipment operations.

Booth Island is rising to 980 m off the northwest coast of Kiev Peninsula in Graham Land, Antarctica (Photo: R. Werner)

The Working Group concluded that there was a general desire to increase the level of observer coverage, recognizing that it was important to identify specific impediments that Members might have to increasing the level of observer coverage. While agreeing on the need for 100% observer coverage, the Working Group concluded that this was a decision by the Commission. While a revision of observer coverage requirements (CM 51-06) was not adopted by the Commission in its last meeting in November 2014, there was agreement to discuss an incremental increase at WG-EMM in 2015.

5. Increased fishing notifications, an observed trend

As stated before, under the current fishing level, the trigger limit might be precautionary but this might change as catches increase due to factors such as the impact of climate change on krill populations and the lack of capacity to estimate total removals by the fishery. The situation becomes even more pressing by taking into account the continuing increase in the capacity of the krill fishing fleet. Not only do vessels using the continuous fishing system have a larger potential daily catching capacity, but also some conventional trawlers have increased their capacity (measured in tons of krill per day) by using two nets simultaneously and/or by improving their krill processing techniques on board.

In addition to these developments, new countries and new vessels are entering the fishery. Even though real catches are normally lower than notified catches, it is clear that the fishing capacity to exceed the trigger level already exists. Therefore, catches can increase up to the trigger level with no further protective provisions in place. Heightened interest in the fishery, increased demand for marine resources and changing technology may lead to more participants entering the fishery in the future. Unless managed properly, the fishery could result in localized depletion of krill that can lead to negative impacts on krill predators proximate to the fishery's operation, or to potentially wider ranging impacts to Southern Ocean food webs and ecosystems.

6. Acknowledgements

The author would like to thank particularly the Pew Charitable Trusts, and especially Gerry Leape, Andrea Kavanagh, Karen Sack & Josh Reichert. Special thanks also to Sue Lieberman (Wildlife Conservation Society), to Mark Epstein, Jim Barnes and Claire Christian of the Antarctic and Southern Ocean Coalition, and to Drew Wright, David Ramm and Keith Reid of the CCAMLR Secretariat.

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Article published in:
Journal of Antarctic Affairs
Volume I
March 2015 / Year I
Editorial Agenda Antártica / ASOC

The Journal of Antarctic Affairs is the academic magazine of the Antarctic and Southern Ocean Coalition (ASOC) and Agenda Antártica, which aims to publish and disseminate the most prominent and influential research in relation to Antarctica. The Journal publishes articles, reviews and official documents in English and Spanish twice a year.