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European naval diets in the sixteenth century: A quantitative method for comparative and nutritional analysis

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ABSTRACT
This paper develops and utilizes novel methods that combine historical records concerning the diets of European naval mariners in the sixteenth century with modern information on the nutritional content of food. Energy, vitamin, and mineral intakes were compared to modern recommended values. Calorie provisions were sufficient and relatively constant in all Western European fleets. The absence of vitamin C was a universal failure of the naval diet. The limiting factor to variety and balance in the naval diet was the demands of preservation with limited technology. Fish declined in importance between the sixteenth and eighteenth centuries while beef increased in importance. A database structure that allows for calculation of nutritional information was designed and utilized in this research and is provided online for future reference and calculation of diets.

KEYWORDS
Food history; nutrition; diet; early-modern navies; naval rations

Introduction

The study of naval diets has many advantages. As Frederic Lane writes, “The diets and wages of seamen are useful historical benchmarks in the history of welfare economics. They are one of the few standards which are stated numerically in the sources” (Lane 1966, 263).

A lack of quantifiable data is often a barrier to forming solid conclusions about patterns of historical diets (Super 2002). Reliable quantifiable and representative evidence for the diet of general populations in the early modern period is difficult to find. Historical records and evidence for the diets of institutions are more readily available. However, most institutional diets are representative of elite or marginal social contexts, such as monasteries or hospitals. The dietary records of naval forces, while also representing a limited perspective, indicate the basic requirements of working able-bodied men. Because the work was fairly standardized across European navies the data lend themselves to comparative study. Changes in the composition of items in the naval diet may provide insight into preservation of food as well as preference for particular foods. Navy vessels were expected to keep at sea for the duration of their mission and did not normally replenish victuals during a campaign.

There are shortcomings of using naval records as a proxy for basic food practices. Food was selected to keep well, and this requirement will have restricted the diet to baked, dried, salted or alcoholic products. In this regard, the naval diet followed patterns that existed within the diets of some terrestrial populations. The diet of the English army in Ireland in the sixteenth century was very similar to that of the navy in the same period. The army ate rations of “wheaten bread, biscuit, oatmeal, beef, and beer, supplemented by butter and cheese,” but soldiers would also have been able to supplement their diets on an opportunistic basis as they roamed through the land (Clarkson and Crawford 2001, 19). English soldiers in Ireland needed to supplement their diet with scavenging in order to survive, as their rations alone did not meet their basic energy requirements (Clarkson and Crawford 2001, 180). Stone masons working in Dublin in the same period ate similar foods to soldiers; bread, salt beef, herring, and cod, but unlike mariners they also drank milk and ate vegetables (Gillespie 1996). The naval diet was peculiar by necessity in its restriction of choice.

Naval fleets typically employed thousands of men and the provisioning of ships was a major logistical challenge that required requisitioning from a vast

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hinterland (Glete 2000, 123). Working out the composition and changes of naval diet will therefore have implications for our understanding of the workings of the early modern economy. The provisioning of beef for the Dutch naval and merchant fleets had significant ramifications for the development of livestock economies in countries such as Denmark and Hungary (Gijsbers and Koolmees 2001). Similar repercussions can be detected for the development of the fisheries. The Nordic Seven Years War (1563–70) obliged the Danish Navy to solicit food from every corner of the Kingdom. The urgent quest for cod seems to have stimulated a boom in fishing settlements and the spread of long-lining technology throughout the country (Holm and Bager 2001).

This research set out to ask if a more systematic approach to the calculation of nutritional information about historical diets could be developed. The methods developed here could be employed to any historical diet for which we have information available, but the naval diet serves as a useful case study in which to develop these methods because it was a more closed system compared to terrestrial diets. This article will focus on the diets of mariners aboard sailing vessels from five of the most prominent navies of northern and western Europe in the sixteenth century: England, Sweden, Denmark, France, and Spain. Data was also sought for the Dutch and Portuguese fleets during this period, but unfortunately we did not find adequate information. Our analysis is confined to naval fleets which mainly operated patrols along the European shores. Such diets would be expected to last the men several weeks up to three months. Merchant ship diets have not been included. Conceivably, ships destined to the tropics to trade in slaves or commodities may have been outfitted quite differently and would have depended on buying food in areas of destination (Dalrymple-Smith and Frankema 2017).

Diets from earlier and later periods were also analyzed as part of this research and will be discussed in order to explore some of the longer-term trends in the developments of naval diets. For example, we compared our findings with the provision for Mediterranean fleets. In general, Mediterranean fleets utilized galley ships with marines and convicts pressed into service as rowers. Compared to this, north-western European navies mostly utilized gun-carrying sailing vessels, without rowers, although galleys were used to make shorter voyages in smaller seas, such as the Baltic (Glete 1993). By the sixteenth century, longer voyages with large sailing vessels were becoming commonplace for most major European navies and the food brought on board ships had to adapt to changing modes of sea travel.

For each study nation we attempted to find the diet that would best represent that of the ordinary mariner, while officers likely had more varied diets.

Methods

In general, historians of this topic (Gradish 1980; Mott 2018; Fury 2012; Phillips 1986; Söderlind 2006; Hamilton 1929) have asked if the naval diet was sufficient to maintain naval mariners in terms of both energy and health. In most cases the same conclusion is reached, that the naval diet was sufficient in terms of calories, but was lacking in critical areas, such as vitamin C. In almost all cases the methods used to calculate the nutrition of these historical diets is obscured from the reader, and historians have used a variety of measures to calibrate the nutritional components of the diet.

This paper has developed a systematic and repeatable database method that combines modern nutritional data with historical information on the volumes of food eaten (Hayes et al. 2019a).[1] The processes used in this database were designed to allow for a transparent view of how the final figures were reached. The database was designed with automation in mind, therefore other users can easily input data on the volumes of food and generate nutritional information. Through this process in our database we can identify the types of food that were most commonly utilized by naval forces and gauge the adequacy and health implications of these diets. We provide all our data freely accessible online in a format that invites future researchers to assess and complement the evidence base.

Each of our calculations is performed by taking historical information about the volume of food eaten by a given number of men, over a given period, and calculating the nutritional content of their diets. Ration records are our best records “for jumping from the general to the particular” (Super 1981, 25).

Naval rations were served in a closed environment, therefore the opportunities for dietary supplementation were limited while at sea. That is not to say there was no supplementation, and we cannot account for personal items brought on board or fish caught at sea. We cannot quantify the supplementation of diet by individuals. However, we can ascertain if a prescribed or apparent diet was sufficient in of its own.

When calculating the nutritional value of historical foodstuffs we are limited by the availability of modern nutritional information. In this study all nutritional values for foods were taken from McCance and

Widdowson's Composition of Foods Integrated Dataset (CoFID) (Finglas et al. 2015). The closest approximate modern foodstuff that matched the historical foods described was selected from this dataset. The values in the CoFID are calculated as averages from several samples of the same foodstuffs, and the method of cooking and preservation is listed for each food. The Selected Modern Foods sheet in our database stores the nutritional values related to our chosen foods. Data is drawn from the Proximates, Inorganics, and Vitamins sheets of the original CoFID dataset.

Every attempt was made within this study to find the closest possible matches between modern and historical foods, but in some instances, we cannot be certain of the accuracy of these counterparts. We were also aware of the need for consistency across our examples. Future studies of this kind could be improved through experimental archeology and nutritional analysis of historical recipes. For example, the Ship Biscuit and Salted Beef Research Project at the Institute of Nautical Archeology in Texas A&M University has conducted experiments to replicate the conditions and preservation techniques of seventeenth-century English naval food. This project hopes to gather "nutritional, microbial, and osteological data" about historical foods from their experiments (Institute of Nautical Archaeology 2018). Similarly, the FOODCULT project, based at Trinity College Dublin, will be conducting experiments to examine the nutritional content of early modern beer (Flavin 2019). Research like this will allow us to more accurately estimate the nutrition of historical diets in the future. However, the methods and information we have access to now do allow us to say a great deal about the diets of mariners in the past and understand the major implications and restrictions that governed them.

The accuracy of historical units is also very important to our results. Historical provisions are expressed in a variety of units and measurements. We converted the volumes of food to a standard weight in grams (g). For instance, our English example from 1565 describes volumes of food in pounds and gallons. In this case the conversions used the modern avoirdupois pounds and gallon which match closely the early modern equivalent (McCusker 1973; Macdonald 2004, 40). One pound of food listed in the source was converted to 454 g in the database. All information on conversions is stored in the Conversions sheet of the accompanying database. This sheet also provides a source for each conversion and contextual information, such as date and type of food associated with certain units.

Many historical foods are listed in units of volume, such as barrels. In our database values are expressed in cubic meters (m^3) or liters (L) and, for nutritional analysis, we converted these units to grams. The weight of a unit of volume will depend on the density of its contents. If the unit of volume contains liquid we assume that it has the same density as water. For example, a Danish beer barrel has a volume of 128 L so we assume that it contained 128 kg of beer (Friis and Glamann 1958, 138).

If a unit of volume contains solid goods it becomes more complex to estimate weight. In the Danish sources bread (or biscuit) is listed as being contained in barrels. According to Friis and Glamann decrees from 1683 to 1698 mandated that the "korntønde" (grain barrel, which was used for bread) have a volume of 139.1 L. However, bread does not have the same density as water so we have to convert volume to weight in rye (the only ingredient of the bread). Mats Morell estimates that the liter weight of early modern rye flour was 0.67 kg, therefore a barrel of rye flour would have weighed 93.2 kg (Morell and Heckscher 1986, 98). To convert this weight of flour to bread we used a ratio of 4/3 of rye flour needed to bake dry bread provided by the Danish writer Niels Morville (Morville 1799, 455–457). Given this ratio between the input of flour and the output of bread we can estimate that the final barrel of bread would have weighed 69.9 kg.

Oftentimes sources will list animal food in carcasses for terrestrial animals and number of individual fish. In these cases, we need to estimate the weight of the animal itself. This process is made more complex by the variety of processing methods that can be used to store animal carcasses. In addition, we have to consider the weight of bones, which would add to the weight but provide minimal nutritional value. The modern average weight of animal carcasses is not reliable for historical information because modern agricultural methods have inflated the weight of livestock compared to the early modern period.

A J S Gibson has estimated the size and weight of "pre-improvement" cattle and sheep in early modern Scotland (Gibson 1988). Figures from the FAO show that modern lamb carcasses have an average edible weight (lean and fat) of 19 kg (FAO 1991, Table 3). Gibson estimates that lamb carcasses from eighteenth century Scotland contained 10.65 kg of edible matter (Gibson 1988, 170). Evidently it is important to seek historically accurate information in this regard, as modern data on carcass weight would lead to overestimation of the nutritional values of historical diets.

In her work on the diets of monks in medieval and early modern England Barbara Harvey brought together estimates of animal weights from a variety of sources (Harvey 2002). Several of Harvey's estimates were used in our calculations. Databases like the Allen – Unger Global Commodity Prices Database provide useful collections of historical units, but more work remains to be done in this area (Allen et al. 2018). It is difficult to be certain of the accuracy of each unit, as in many cases we have limited information about the exact nature of historical units. To help quantify this uncertainty each conversion was given an accuracy rating from one to three. Conversions we were certain of were given a rating of three. A rating of two indicates a conversion that is likely accurate, but could be improved. A score of one was given to those conversions that require the most improvement with better information. This rating system allows users to understand which conversions can be made more accurate. In addition, the structure of the database was designed to allow for quick recalculation using new or improved conversions.

The Input from Primary Sources sheet combines the different elements of our data to produce the output figures. In this sheet the user can input the core information for each specific example. The whole database is designed to automatically update from the inputs in this sheet using Microsoft Excel's functions. Decisions on the types of food and the conversion factors can be quickly changed in this sheet.

To show how the database works, we may consider a supply list for the Danish ship the Mikkel from 1538 (Tegnelser over alle Lande for 1538, Danske Magazin 1860). The supplies listed were meant to last for three months for 549 crew members. For this period, 1,779 barrels of beer were provisioned. As mentioned earlier, a Danish beer barrel had a volume of 128 L (Friis and Glamann 1958, 138). Again, we assume that a barrel with a volume of 128 L contains 128 kg of beer.

In order to match the values from the CoFID, each volume of food is divided into 100 g units. The following calculation is performed using the inputs discussed:

$$\frac{128*1,779}{549*90}*10 = 46 \ units \ of \ 100g \ per \ day \ per \ man$$

Or more generally:

$$\frac{Unit \ Weight \ (kg)*No \ of \ Units}{No \ of \ Men*No \ of \ Days}*10 = No \ of \ 100g \ units \ per \ day \ per \ man$$

The 46 units of 100 g are then multiplied by the nutritional value of 100 g of beer from the nutritional database, which equates to:

$$46*30 = 1,380 \ kcal \ per \ day \ per \ man$$

Again, more generally:

$$No. \ of \ 100g \ units \ per \ day \ per \ man*Calories \ per \ 100g \ unit = kcal \ per \ man \ per \ day$$

This calculation is repeated for every foodstuff in our historical diet and every nutritional element found in the Proximates, Inorganics and Vitamins sheets in the CoFID. Through this process we can estimate the total nutritional content of a historical diet. These data are then displayed in the Output sheet. From this sheet we can query and generate more detailed results about daily nutritional intake. Detailed pivot tables for each nation, showing daily and weekly consumption can be found in separate sheets of the database.

The benefit of this approach is the ability to quickly recalculate figures if more reliable metrological or nutritional information is uncovered. The process described above is fully automated in the database. The static version of our European Naval Diets Database, as used in this research, has been provided in full online (Hayes et al. 2019a). Other researchers can use this version to access the information described here, and add their own examples. In addition, we have developed a website to host a Historical Diets Database (Hayes et al. 2019b), this version contains all the same data utilized in this paper, but will be added to in the future with additional examples of historical diets. We have also developed and hosted an online tool called the Historical Nutrition Calculator based on the methods described here. This tool allows a user to input historical dietary information in a web browser, choose units, and modern food equivalents and generate own results (Hayes 2019c).

Our database was designed to clearly indicate where subjective decisions were made and provide justification and sources for those decisions. Each diet analyzed can be traced back through the database to the original source material.

The quickest way to test if a historical diet met the energy requirements of those who consumed is to compare the energy values to modern dietary reference values (DRV). DRV is an umbrella term for a series of concepts which all correspond to the same idea; a value for "an individual nutrient that people need for good health depending on their age and gender" (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2017). However, there are concerns about the suitability of comparing modern DRV to historical situations and diets.[2] Clarkson and Crawford state that skepticism is based on the fact that DRV have been recalculated over time and there are marked differences from country to country (Clarkson and Crawford 2001, 174). It could be argued that DRV reflect our modern standards of nutritional intake and might not be appropriate for historical cases. John C Super points out that ideally we would calculate the actual energy needs of our subjects. Sherburne Cook and Woodrow Borah did this in the case of American Indians in the sixteenth century (Super 1981; Cook and Borah 1979). Sixteenth-century naval mariners were likely shorter and lighter than modern individuals, which would tend to reduce their dietary needs, while hard labor and insufficient heating tended to increase their needs.

Historical diets and nutritional values have also been used to study purchasing power and standards of living in different regions across time. These methods can provide a valuable insight into the standards of living in the past. To study purchasing power over time Robert C Allen constructed a bare bones basket of goods that an individual would need to survive, including food. He calculates the nutritional values of the food in his basket in order to understand the average calorie intake of people subsisting on those items (Allen 2001). Allen's basket yielded a total of 1,941 calories per day. Allen uses this same figure in this study of living stands in China from 1738–1925 (Allen et al. 2011). Frankema and van Waijenburg (2012) also employ Allen's figure of 1,940 calories per day in their study of the structural impediments to African Growth. By modern standards this energy intake would be insufficient for most of the population. Based on the European Food Safety Authority (EFSA) recommendation, this would be closer to that required by a child under 10 (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2017). The methods and figures used by Allen and others provide a useful benchmark to test purchasing power over time, but the methods used to calculation the historical nutritional values could be improved by using more systematic and transparent approach, such as the one developed in this paper. It is our hope that by describing our methods and providing our database and tool online, researchers who want to include some aspect of historical nutrition in their research can easily employ our methods.

In the case of naval diets, we know from documentary sources and archeological remains from naval warships that most of the mariners aboard naval vessels would have been adolescent and young men. For example, registers of naval crew members from the French port of La Rochelle in the 1680s show that all crewmembers were male, with most being in the twenties or thirties, each ship also had a number of boys in their teenage years on board (R Rôles d'équipage et des maîtres, matelots, pêcheurs, mariniers 1682–1696). Direct Archeological evidence backs up the documentary records. The English naval warship the Mary Rose sank off the Isle of Wight on the 19 July 1545. The ship was excavated in the 1980s and 179 individuals were recovered and identified from the wreckage. All the skeletons were male, with 17 being identified as adolescents, below the age of eighteen, a further 54 were young adults, between the ages of eighteen and thirty, a further 15 were identified as middle adults, aged thirty to forty (Stirland 2012, 54–55).[3] For this reason we used the appropriate DRV values for adolescent and young men in our research.

We adopted an approximate range of from 3,300 kcal for the average sailor up to an upper bound of 5,100 kcal as indicative of a sufficient diet. By the standard of the EFSA report, a very active male between the ages of 18–29 is recommended to consume 3,344 kcal per day, and this value drops as we age. The highest recommended intake is for a very active 17-year-old male, at 3,678 kcal per day (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2017). Early twentieth-century figures indicate a wider range: In 1912–13 the Swedish Army calculated the dietary needs of a soldier at 3,300 kcal, while the physiological needs of a hard-working 20-year old male with a body weight of 100 kg might be estimated as high as 5,061 kcal (Morell and Heckscher 1986, 7). In the absence of detailed information on the energy needs for each subject, and given the geographical and temporal spread of our examples, modern DRV may, however, serve as a very useful and consistent benchmark to which we can compare different examples of historical diet. An excess energy consumption of 100 kcal/day would increase body weight by almost 3 kg in a year. Information on our chosen DRV is stored in the DRV sheet of the database. A comparison was then made between each of our nutritional results and its corresponding DVR. Some of the more important discrepancies between our results and the modern standards will be explored in further detail later.

Data

We use evidence for both prescribed (rations) and apparent consumption (supply lists) in our examples. The prescribed diets, by definition, have greater representability as they were designed cover provisions across the fleet. However, prescriptions may be prone to fraud as well as substitution of one food item by another. Apparent diets represent actual consumption on a ship and are therefore highly trustworthy but may not be representative. The two types of data may be mutually supportive if the overall picture of consumption is similar.

Prescribed ration records are the most precise dietary records we have, and they show us the "minimum dietary standards as perceived by those recommending the rations" (Super 1981, 25). Ration lists, such as those we have from the English navy in 1565, also provide a straightforward opportunity to convert figures from historical documents to modern nutritional values because they list consumption as daily values, often in weight of food per crew member. Supply lists present a more complex challenge to convert to modern standards, as we need to know the number of crew and the length of time the supplies were meant to last, as well as expected wastage in order to estimate daily nutritional values.

Our sixteenth-century English diet is reconstructed from an admiralty statute that prescribed the diet of Royal Navy mariners for a week in 1565 (Rodger 1997, 235). This was the diet of ordinary seamen and was intended to be provided by the admiralty's victualers. The Spanish example is based on the typical rations of Spanish sailors for one week in the trans-Atlantic treasure fleet from the year 1560 (Hamilton 1929, 434). The Swedish example is based on work by Ulrica Söderlind, and represents the likely meal arrangements for Swedish sailors in the Baltic in the year 1546 (Söderlind 2006, 109). We made one edit to the arrangement proposed by Söderlind as we reduced the bread intake from 1 kg to 643 g to reflect the average intake of bread proposed by the author herself (Söderlind 2006, 104). The Danish example is based on a 1557 list of supplies by the Danish admiralty for a vessel to patrol the North Sea and Eastern North Atlantic (Bricka 1887–88). Finally, the French data are based on a list of supplies needed to maintain a crew of 250 men for three months, compiled by the French geographer Nicholas de Nicolay in 1582. The diet described by de Nicolay was from a ship in the French Atlantic fleet and was designed to support sailors and soldiers "to make some long trips to discover new lands" (de Nicolay 1582, 32–33). Some of our examples, like the English and Spanish, were calculated on the basis of a weekly diet, but we present all figures as daily averages. For comparative purposes we also analyzed naval diets from Mediterranean fleets in the medieval period. We calculated the diets of Venetian, Angeivina, and Catalan-Aragonese galleys (Mott 2018, 2003; Pryor 1994; Lane 1966).

Naval diet in sixteenth-century Europe

On the basis of regulated rations and supply lists, we may summarize daily energy consumed per crewmember for each of the selected navies (Table 1). The prescribed rations of the English and Spanish navies align very well with the expected rations to keep a slender, hard-working sailor nourished. However, cultural and geographic differences between the two fleets are evident. The Spanish drank wine and their diet included olive oil and chick peas. In comparison the English drank beer and ate herrings, with this particular fish species not being readily available to southern fleets. Despite these differences they are strikingly similar in terms of the composition of protein, fat, carbohydrate, and alcohol. The estimated daily diet of the Swedish navy resembles that of the English and Spanish, except for a very high consumption of carbohydrates in the form of both bread and groats (pearl barley).

In all instances we cannot know for certain how much of the food provided would have actually been consumed. However, our results can tell us if the food brought on board was enough to cover the energy needs of the crew. We should note that all our records based on supply lists exceeded modern recommended calorie intakes and are higher than those based on prescribed diets. This is what we might expect, as a certain amount of a ship's supplies could be expected to be lost through the cooking process or by rotting and spoiling by sea water and other contaminants. In addition, the naval suppliers themselves may have

Table 1. Daily energy consumption for Northern European fleets.

Example	Type of data	Protein (g)	Fat (g)	Carbohydrate (g)	Alcohol (g)	Energy (kcal)
Danish Naval Diet, 1557	Supply list	534	125	1,125	186	8,858
French Navy Diet, 1582	Supply list	395	35	355	217	4,805
Swedish Naval Diet, 1546	Daily diet estimate	111	59	812	87	4,637
Spanish Naval Diet, 1560	Regulated ration	195	46	513	130	4,043
English Naval Diet, 1565	Regulated ration	216	89	401	110	3,962

overcompensated the amount of food needed for one month in order to avoid disaster if the ship had to stay at sea longer. Logically, we may expect calculations based on supply lists to exceed the needs to provide for actual daily rations. For example, we know that eighteenth-century slave ships would stock up with much more food than used on average, simply to minimize the risk of delays and to maximize the survival rates of the human cargo (Dalrymple-Smith and Frankema 2017).

The French navy supply list matches this expectation also. The calculated daily energy consumption of 4,785 kcal may be explained by the fact that the supply lists needed to take account of waste due to rot and discard. The composition of the diet was relatively high in protein and alcohol relative to the English and Spanish, while lean in terms of fat and carbohydrate.

The Danish energy intake is, however, quite outlandish, at 8,858 kcal per day. Extensive research was conducted to improve the units of conversion for the Danish supply list. Even allowing for inaccuracy in our conversion units, the amount of protein and bread prescribed by the Danish admiralty was excessive while the consumption of alcohol and fat was not wide off the European standard. We may find a clue to the discrepancy in the preamble to the provision list: "Last time, when they provisioned the naval vessels, there was much disorder in the food supplies, so that much more rations were used than necessary." The list nevertheless goes on to require supplies that are virtually identical to the previous regulation from 1551 (Bricka 1885–86, 1887–88). The only difference is that half a sheep's carcass was rationed per man in 1557, compared to a full sheep's carcass in 1551. This amounted to a difference of 88 kcal per day. We do not know if systematic fraud was behind the excessive provisions but there does seem to have been something rotten in the Danish state.

Given that supply lists overestimated the amount of food needed to just sustain the crew, we might ask if applying a general reduction to account for wastage and oversupply is appropriate. In her study of Monastic Diet Barbara Harvey asks how much of the monk's food would actually have been consumed. Harvey found that monks in fifteenth century England ate far in excess of modern recommended values, with a typical meal consisting of 4,470 kcals (Harvey 2002, 69). In the monastic setting the peculation of food was part of the economy of the monastery, with servant's consuming at least some of the food meant for the table (Harvey 2002, 67). A similar situation could have existing aboard ships, but probably not to the same extent as every crewmember should have been accounted for in the daily supplies. In order to account for wastage and the consumption of servants Harvey makes a "reasonable assumption" that 25 per cent of all the food served went to waste. This reduction brings the daily average to 3,350 kcals, much closer to modern recommended values. If we apply the same general reduction to our examples based on supply lists we find the French naval diet drops to a daily average of 3,603, which is far closer to recommended values. The Danish diets drops to 6,644 which is still far in excess of a reasonable diet. Ultimately it is difficult to accurately quantify wastage and verify if a general 25% reduction like this is appropriate. We simply have to keep in mind that supply lists will in general contain a buffer zone in terms of energy to help avoid disasters.

We may compare these rations to Mediterranean findings. Soldiers on-board the Tuscan galleys in the sixteenth century received a ration of 400 g of biscuit per day, along with salt meat, olive oil and wine. Convicts, forced to row the galley as punishment, received a ration of 600 g of biscuit per day. They also received a ration of water and bean soup on a few occasions during the week. This ration of biscuit would have amounted to 2,779 kcal per day and would have been insufficient to provide rowers with adequate energy, let alone maintain good health (Hémardinquer 1970, 89). With some other rations like bean soup included, the rowers' diet may just have been sufficient to maintain them in the short term. As Hémardinquer (1970, 89) writes; "The Tuscan Navy did not ignore the needs of the living engine, but satisfied them, even on paper, with the greatest economy." The same level of economy was not applied to officers, who were provided a daily diet in excess of 6,000 kcal. Tuscan marines had a more varied diet and consumed on average 3,298 kcal per day, which is closer to modern recommended values.

While our study focuses on the mean dietary composition but there is no doubt that social standing would have been reflected in the diet. The admiral on the Mary Rose had his own personal dinner service for his meals and he and his officers would likely have had a richer and more varied diet than the majority of the crew. The nutritional range on all vessels of the time would likely have been huge.

Composition of the diet

Energy values alone do not indicate a healthy, balanced, or sufficient diet. Energy from food is almost

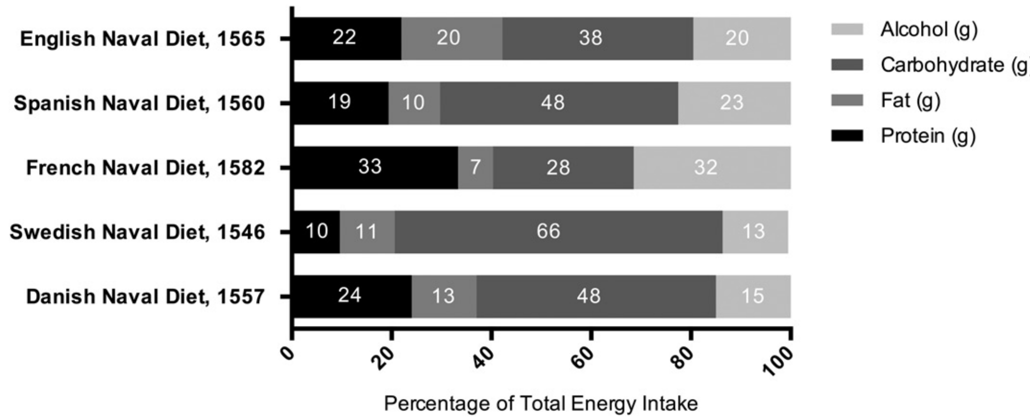

Figure 1. Percentage energy contribution from protein, carbs, fat, and alcohol (kcal).

entirely made up of four sources; protein, fat, carbohydrates, and alcohol. In simple terms, each gram of carbohydrate contains 3.75 kcal/g, each gram of protein contains 4 kcal/g, fat contains 9 kcal/g, and alcohol contains 7 kcal/g (Finglas et al. 2015, 12). EFSA recommends a certain balance of energy sources, e.g. 45–60% of a male adult's daily calorie intake should come from carbohydrates and 20–35% should come from fat.

Figure 1 shows the percentage contribution from each type of energy source for each example. As can be seen, carbohydrates make up the bulk of the calories in almost all examples. The Spanish diet almost gets the balance right, with the Danish diet being very similar. The English diet is just slightly below the modern recommended values, while the French diet has the lowest carbohydrate value, owing to a higher proportion of protein and alcohol. The Swedish diet has a very high carbohydrate intake and a proportionally lower alcohol intake. The Swedish diet contained both rye bread and groats, which are the kernels of cereals. These foods contribute to a high carbohydrate-based diet. Fat intake may have been higher if we assume fattier cuts of meat in our analysis. Salted meat is one of the hardest items to find a modern equivalent for, as we simply do not preserve and consume meat in the same way today.

Carbohydrate

Bread, or ships biscuit as it is also known, is the most ubiquitous item across all our examples.[4] It is also one of the more difficult historical foods for which to find a real modern equivalent. In port, mariners consumed ordinary soft bread, but at sea and during long voyages, ship's biscuit was consumed. The nutritional content of any bread is a reflection of the cereal used to make it. Soft bread has a water content in the region of 35–40%, but ships biscuit has a much lower water content than this. The low water content of the ship's biscuit meant that it would last considerably longer than traditional bread before going bad. This was the main advantage of the ship's biscuit over traditional bread. The Castilian statutory code from c. 1260 referred to biscuit as "a very light bread for transport because it is baked twice and lasts longer than others and does not spoil" (Mott 2018, 5). The word biscuit originates from this practice, the Italian "biscotti" translates to English as "twice baked." The French writer Pingeron wrote the ship's biscuit was baked twice for short voyages, and up to four times for longer trips (Pingeron 1780, 192). He goes on to describe the process of making the biscuits and writes that the wheat dough was made into circular cakes of 24 inches in diameter, which weighed 9 ounces after cooking. He states that the biscuit was best stored in dry barrels, sometimes lined with sulfur for pest control (Pingeron 1780, 192–202).

Historical recipes from Pingeron and others indicate that flour and water were the only ingredients of ship's biscuit. Reconstructions of this recipe have shown that the final product had a water content of around 5% (Pavlik 2011, 8). Therefore, we decided to use raw flour to calculate the nutritional contents of the dense ship's biscuit in all our examples. The simplicity of the recipe for ship's biscuit means we can be confident in the nutritional makeup of it, the main issue being the density of the biscuit as raw flour may be denser than actual biscuit. Using the nutritional data from modern breads would not be appropriate because of the higher water content and the fact that many breads today are fortified with additional vitamins and minerals.

Rye and wheat flour contributed the majority of the carbohydrates in these diets. In fact, ship's biscuit was an item found in every example we analyzed from the thirteenth to eighteenth century. In

Denmark and Sweden, rye flour was most commonly used to bake bread and make ship's biscuit. In France, Spain, and England, wheat flour was the most common cereal. Table 2 shows the foods that contributed the most carbohydrates in our examples (all numbers have been rounded to the nearest tenth).

Biscuit was not the only source of carbohydrate in our examples. Early modern Spanish ships sometimes also carried rice, and while this item was not present in our example from 1565, it is found in a Spanish diet compiled by Carla Rahn Philips from 1630 (Phillips 1986, 242). A full analysis of this diet can be found in the accompanying database. Our Scandinavian examples both include pearl barley. Oatmeal became a common item in the English shipboard diet in the eighteenth century. But despite some variance, it was the biscuit that formed the bulk of carbohydrate intake in every example we examined.

The main sources of carbohydrate in the naval diet remained remarkably stable across all examples. The ubiquitous ship's biscuit was the most specialist food eaten by mariners and was not an item eaten commonly by terrestrial populations, outside of siege or military situations. There was simply no need to consume biscuit over traditional bread in everyday life. Its prevalence in the maritime diet is a reflection of limited technology, the need for preservation, and the physiological necessity for carbohydrates. While other items of shipboard food might have been coveted by the mariners, such as alcohol and meat, the ship's biscuit created a source of carbohydrate that was both long lasting and unappealing in equal measure.

Table 2. Major sources of carbohydrates in sixteenth-century naval diets.

Example	Percentage food contributed to total carbohydrate intake
Danish Naval Diet, 1557	100%
Flour, rye	76
Beer, bitter, average (<4% ABV)	13
Barley, pearl, boiled	6
Peas, split, dried, boiled in unsalted water	5
English Naval Diet, 1565	100%
Flour, wheat, wholemeal	79
Beer, bitter, average (<4% ABV)	21
French Naval Diet, 1582	100%
Flour, wheat, wholemeal	46
Cider, dry	36
Beans, broad, dried, raw	6
Beer, bitter, average (<4% ABV)	6
Other	6
Spanish Naval Diet, 1560	100%
Flour, wheat, wholemeal	93
Beans, broad, dried, raw	7
Swedish Naval Diet, 1546	100%
Flour, rye	83
Barley, pearl, boiled	9
Beer, bitter, average (<4% ABV)	8

Protein

While the sources of carbohydrates in the naval diet remained remarkably stable over the centuries, sources of protein were more changeable and varied between different nations and periods. Protein is important in the human diet not only as a source of energy but also for the building and repairing of muscles. The EFSA population reference intake (PRI)[5] of protein for adults between 18 and 59 years old is 0.83 g of protein per kg of body weight. The mean height of a sailor on the Mary Rose, based on the skeletal remains was 171 cm (Stirland 2012, 55). An average healthy weight for a man of this height is around 70 kg. The EFSA recommendations suggest a 70 kg man requires 58.1 g of protein per day. If we refer back to Table 1 we find that almost every example analyzed had at least three times this daily protein intake.

Our analysis of the predicted diet for the Mary Rose sailors suggests they received on average 340 g of protein per day. Coy and Hamilton-Dyer (2005, 608) observe that a meat-rich diet was felt to be necessary in the English Navy to support the heavy manual work that many members of the crew would have to perform. Again, the skeletal evidence of the Mary Rose supports this assertion. For example, the skeletons of a gun crew were identified in the wreckage. Five of the skeletons recovered from this crew were young men with "strong, robust and with well-muscled skeletons" (Stirland 2012, 72). In addition, evidence from the spines of these men, and others, indicate a life of hard manual labor. There are also indications that many of the men trained extensively to draw a longbow, which could have a draw weight of up to 75 kg and would require substantial strength to use (Stirland 2012, 69). If we look at protein in isolation these men would have been consuming enough to aid muscle repair and recovery.

Table 3 shows the major protein sources for our sixteenth-century examples. Naval suppliers would have made distinctions, as we do today, between plant foods and meat. Wheat has about half the protein of meat and fish, with 11.6 g of protein per 100 g of wheat flour, but it appears high on these lists because of the sheer volume eaten per day. However, not all sources of protein are equally useful to the body. Certain proteins are higher quality than others. The method used to calculate protein quality has recently been updated and is described in a report published by the Food and Agricultural Agency of the United Nations (FAO 2013). The quality of a protein depends on the level of digestible amino acids in each food. Specific scores for beef and fish are not given in this

Table 3. Major sources of protein in sixteenth-century naval diets.

Example	Percentage food contributed to total protein intake
Sweden	100%
Flour, rye	60
Pork, belly joint/slices, grilled, lean and fat	17
Beer, bitter, average (<4% ABV)	8
Herrings, dried, salted, weighed with bones and skin	8
Barley, pearl, boiled	7
France	100%
Beef, salted, dried, raw	71
Herrings, dried, salted, weighed with bones and skin	14
Flour, wheat, wholemeal	7
Beans, broad, dried, raw	5
Other	3
Spain	100%
Flour, wheat, wholemeal	40
Beef, salted, dried, raw	28
Beans, broad, dried, raw	14
Cod, dried, salted, boiled	11
Other	7
England	100%
Beef, salted, dried, raw	33
Flour, wheat, wholemeal	24
Cod, dried, salted, boiled	21
Cheese, hard, average	11
Beer, bitter, average (<4% ABV)	5
Herrings, dried, salted, weighed with bones and skin	4
Other	2
Denmark	100%
Beef, salted, dried, raw	47
Flour, rye	16
Pork, belly joint/slices, grilled, lean and fat	12
Herrings, dried, salted, weighed with bones and skin	8
Lamb, average, raw, lean and fat	7
Other	10

Table 4. Major sources of animal protein in sixteenth-century naval diets.

Row Labels	Percentage food contributed to total animal protein intake
Spanish Naval Diet, 1560	100%
Beef, salted, dried, raw	62
Cod, dried, salted, boiled	24
Cheese, hard, average	14
Swedish Naval Diet, 1546	100%
Pork, belly joint/slices, grilled, lean and fat	69
Herrings, dried, salted, weighed with bones and skin	31
French Naval Diet, 1582	100%
Beef, salted, dried, raw	82
Herrings, dried, salted, weighed with bones and skin	17
Other	1
English Naval Diet, 1565	100%
Beef, salted, dried, raw	47
Cod, dried, salted, boiled	30
Cheese, hard, average	16
Herrings, dried, salted, weighed with bones and skin	6
Other	1
Danish Naval Diet, 1557	100%
Beef, salted, dried, raw	62
Pork, belly joint/slices, grilled, lean and fat	15
Herrings, dried, salted, weighed with bones and skin	11
Lamb, average, raw, lean and fat	9
Haddock, flesh only, grilled, fillets weighed with bones and skin	2
Other	1

report but in general animal proteins score more highly due to better levels of essential amino acids (FAO 2013). Wheat protein is lacking in the essential amino lysine, limiting its usefulness as a protein source for human consumption (Shewry and Hey 2015, 182).

Table 4 shows the major sources of animal protein in our sixteenth-century examples. Most diets included staple items like biscuit and alcohol, but protein varied much more day to day. The most common sources of animal protein were salt beef, pork, bacon, and fish. Like other foods consumed in the navy, the preservative qualities of salted meat and fish made them an ideal source of long lasting protein. Like biscuit, the process of salting, brining, and drying fish and meat would prevent microorganisms from accessing the flesh, allowing it to last much longer.

Almost all regulated navy diets included a mixture of fish, meat, and cheese days. The distribution of these days differed between all our examples, and a full breakdown can be seen in the database. Beef was the highest contributor in four countries, England, Denmark, France, and Spain. All our examples also included a certain amount of dried or salted fish. The Danes had the largest variety of fish in their diet, with plaice, herring, haddock, and cod all being included in the supply lists in some amount. Among all other examples salted cod and herring were the most commonly found fish and appear prominently on these lists, although second to beef and pork in all cases.

While comparative evidence indicates that the intake of carbohydrates was remarkably stable through the medieval and early modern period, the composition of protein sources showed interesting variation. Significantly, there seems to have been no fish in the diets of medieval Mediterranean galleys. In relation to the Catalan-Aragonese Fleet, Lawrence Mott writes that he finds the lack of any fish surprising, as "Sicily had a substantial fishing industry regulated by the Crown." He concludes that "either the availability or cost must have been the controlling factor for the absence of fish" (Mott 2018, 8).

While all our sixteenth-century northwest European examples included fish of some sort and in varying amounts, four example diets from the late seventeenth and early eighteenth century show a lack of fish in naval diets (Table 5). These examples seem to reflect a

Table 5. Major sources of animal protein in seventeenth and eighteenth-century naval diets.

Example	Percentage food contributed to total animal protein intake
English Navy Weekly Provisions, 1689–97	100%
Beef, salted, dried, raw	64
Pork, belly joint/slices, grilled, lean and fat	16
Cod, dried, salted, boiled	15
Cheese, hard, average	5
Swedish Naval diet, 1700	100%
Beef, salted, dried, raw	85
Pork, belly joint/slices, grilled, lean and fat	10
Herrings, dried, salted, weighed with bones and skin	4
Other	1
English Naval Diet, Eighteenth Century	100%
Beef, salted, dried, raw	75
Pork, belly joint/slices, grilled, lean and fat	19
Cheese, hard, average	6
Daily ration of a militiaman in Saint-Malo, 1759	100%
Beef, salted, dried, raw	99.7
Butter, unsalted	0.3

wider trend away from fish. By 1700 a large proportion of the Swedish protein intake came from beef. Ulrica Söderlind observes that a decline in the supply of fish to the Swedish navy started in the 1660s and 1670s. Söderlind believes that this had nothing to do with the decline of remaining Catholic practices in Sweden in this period, and suggests that a rise in the cost of Norwegian cod, and the cost of the butter used to prepare it, led to the demise of cod as a naval supply. In addition, she notes, "Admiralty Board did not consider fish as good as other provisions" by the late seventeenth century (Söderlind 2006). A similar decline in the consumption of fish can be observed within terrestrial Swedish populations, but "60–70 years earlier in the navy" (Söderlind 2006, 257).

The French example diet in Table 5 was intended for militiamen defending the fort of Saint-Malo in 1759. The diet for these men was "established on the basis on which the Navy has always been in the habit of doing" (Flippini 1970, 97). This French example has the highest percentage of beef out of all the examples, and like the others from this period, contains no fish. This was the only terrestrial diet examined in our study, but it shows the potential for expanding the analysis into other diets intended for close environments, such as sieges.

In 1677 Samuel Pepys drew up a new naval diet for the English Admiralty. It included three fish days per week, on which either cod or hake was eaten (Macdonald 2004, 9). A similar list from 1689 to 1697 includes three fish days per week, on which cod was eaten, but oatmeal could be substituted in periods when fish was scarce (Ehrman 1956, 121). Compared to the English naval diet from 1565 cod now made up a lower proportion of the total protein.

After 1733, cod was no longer part of the official ration list for the Royal Navy. It was still sometimes eaten, but was dwarfed by the consumption of beef and pork. Between 1750 and 1757 the Victualing Board in England collected figures about the volume of different naval supplies. Over the period from 1750 to 1757, 54,642,437 lbs of bread and 110,049 tuns of beer were provided to the Royal Navy. In addition, 4,498,486 lbs of beef and 6,734,261 lbs of pork were delivered. In comparison to this, only 166,943 lbs of cod were supplied (Rodger 1988, 83). These figures show that total weight consisted of 39% beef, 59% pork, and 1.5% stockfish (Roberts et al. 2012, 3). At the same time the Victualing Board also collected figures on how often different food stuffs were found to be rotten and inedible on the opening of the casks they were contained in. The figures from this report indicate that no foodstuff, other than stockfish (air dried cod), decayed more than one percent of the time (Rodger 1988, 84–85). In comparison, 7.9 percent of cod supplies were found to have decayed before they could be consumed.

Around this time the Admiralty in England declared that mariners "should be supplied with the best of everything in its kind" (Rodger 1988, 85). So it would appear that the unreliability of cod was a major factor in its decline as a naval ration. In addition, it was thought at the time that salted provisions contributed to the onset of scurvy among mariners (Macdonald 2004, 38; Locker 2016, 102). In the ration lists from 1733 cod was replaced by oatmeal, which remarkably is not a comparable source of protein (Rodger 1988, 83). As can be seen in Table 5, by the mid eighteenth century, beef, pork and cheese were the major sources of animal protein in the English naval diet. However, further research will need to be done to gauge whether price was a factor in the decision by naval forces to drop fish from their supply lists (Locker 2016, 104). It is also possible that the quality of dried and salted cod changed over time and that this influenced the decision to drop it from ration lists.

Alcohol

Alcohol was an important part of the naval diet in the early modern period. There is regional variance in the amount and type of alcohol consumed within our examples, but every example contained alcohol in some form. Table 6 shows the major source of alcohol in each of our sixteenth-century examples.

Table 6. Major source of alcohol in sixteenth-century naval diets.

Example	Type of alcohol	Liters per day	Average g of alcohol per day
English Naval Diet, 1565	Beer	3.8	110
Swedish Naval Diet, 1546	Beer	3	87
Spanish Naval Diet, 1560	Wine	1.2	130
French Naval Diet, 1582	Cider	5	190
Danish Naval Diet, 1557	Beer	6.4	186

Alcohol is an energy dense substance, with 7 kcal/g, but is less accessible than carbohydrates and must be processed by the liver. Alcohol is processed at about a rate of about one pint per hour, excess alcohol remains in the blood stream causing drunkenness. About five per cent of alcohol consumed is excreted in the urine, but we decided to include all calories from alcohol in our totals (Smolin and Grozvenor 2013).

Beer was the most common drink among the northern European naval powers, while southern European fleets most often carried wine. French ships often carried a mixture of wine, beer, and cider, as in our sixteenth-century example. Later in the eighteenth century the number of alcohol beverages brought aboard naval vessels expanded. For example, rum became a common substitute for beer when vessels operated in the Caribbean (Rodger 1988, 73). However, beer remained the staple drink of most northern European fleets.

The alcohol percentage of the beer drunk by naval personnel is an open question. Beer was also an important dietary component for terrestrial populations in early modern Europe. Beer was considered a healthy drink in early modern England and was universally consumed because fresh water was seen as potentially harmful. Beer was perceived as particularly helpful for working laborers (Muldrew 2011, 65–66).

However, alcohol held extra significance in the maritime setting. Terrestrial populations could drink water if necessary, while naval personnel were limited to whatever they brought on board. Fresh water barrels would go bad within days of being left in a ship's hold. Sealed barrels of beer and other alcoholic drinks would last far longer before going bad, and provided a vital source of water to mariners. Beer stored in barrels for long periods would have gone sour, but would have still been fit for human consumption. In addition, as we have seen, alcoholic drinks were an important component of the energy intake of naval personnel.

The energy value and alcohol percentage of naval beer is an open question without a clear answer. The debate around beer is a good example of the difficulty in reconstructing historical diets accurately. Craig Muldrew estimates the alcohol and calorific content of different beers in early modern England. He suggests that weak or "small beer" had an alcohol content of 2% and contained 200 kcal per pint (.473L). Muldrew says this type of beer was primarily given to children and says it did not last as long as stronger beers, but "would have been preserved by hops to an extent" (Muldrew 2011, 73–74). An average of modern bitter beers with less than four per cent alcohol contain 142 kcal per pint. Muldrew estimates that a middle strength beer had an alcohol content of 5–7% and contained 400 kcal per pint. This was the type of beer most commonly given to workers. A modern pint of bitter beer above 5% alcohol contains 199 kcal per pint. Muldrew states that due to lower levels of fermentation early modern beers contained more residual sugar from malt compared to modern beers. This would mean that early modern beer had a higher energy contents from sugar at the same alcohol levels compared to modern beer.

Using these figures Muldrew does his own calculations for the English naval diet from 1565. Muldrew uses his estimate of 400 kcal for middle beer, which results in a daily intake of 3,200 kcal from the 8 pints of beer included in the rations. Our results, using modern bitter beer below 4% produced results of 1,136 kcal per day. Given these results Muldrew's calculations for the energy value of naval beer seem unrealistic. His total daily intake amounts to 7,230 kcal when 1 lb of biscuit and 2 lb of salt beef is included (Muldrew 2011, 124). Our estimate for the same intake of food is 4,890 kcal[6], different energy values of beer and bread account for most of the difference. Our figures produce a more believable result in terms of energy given what we know today about the requirements of a working man. Muldrew does not use the less energy dense small beer in his example because he believes it did not last as well as stronger beers, and middle beer was seen as standard for working men.

However, Janet Macdonald claims that the English navy in the Eighteenth Century did consume small beer, with an alcohol content of 2–3% (Macdonald 2004, 40). A recipe from the seventeenth century instructs that naval beer drunk at sea should contain

18 quarters of malt and 18 quarters of hops. Beer for harbor consumption should contain 20 quarters hops and "a sufficient quantity of very good hops, to keep for the time of its warranty" (Ehrman 1956, 146). As this quote attests, the high ratio of malt to hops was necessary to increase the shelf life of naval beer. Hops contain both humulon and lupulin, which kill many harmful microorganisms and may have helped preserve the beer in the absence of a high alcohol content (Muldrew 2011, 67). High levels of hops would have made the beer very bitter. Ulrica Söderlind also states that Swedish mariners drank a beer with 2.1% alcohol content. Brewing supply lists from Sweden in 1599 also show a high ratio of malt to hops for naval beer. Beer for seafarers contained twice as many hops as beer brewed for soldiers in the same year, underlining the importance of hops to preservation in the naval context (Söderlind 2006, 51–52).

For our calculations we used an average of five modern bitter beers with an alcohol content less than four per cent (Finglas et al. 2015).[7] As stated, this average contains 142 kcal per pint (30 kcal per 100 g). Alcohol content in this beer is close to that of a small beer, but it is still less energy dense than the Muldrew estimate for the same. Modern beer undoubtedly contains less hops than the early modern equivalent, and likely also less energy for the same alcohol content, but we believe this equivalent provides the best balance between energy and alcohol in our calculations. Reconstructions of historical beer recipes for naval fleets could provide better information in the future.

Among our examples the Swedish, Spanish and English had a very similar intake of alcohol. The Danish and French had the highest daily alcohol intake on average, but as mentioned both these examples are based on supply lists, so we must account for oversupply. Table 6 shows the daily intake of alcohol in our core examples.

Recommendations for safe alcohol intake vary between countries. The most recent guidelines from the UK's Chief Medical Officers recommended that both men and women should consume no more than 14 units of alcohol in one week to avoid health risks from excess consumption (Department of Health 2016). One unit is equal to 8 g of alcohol, therefore the weekly recommended intake is 122 g of alcohol per week. As we can see from Table 6 only the Swedish did not consume in excess of the weekly limit in a single day! The weekly total for the Swedish example would still amount to 609 g of alcohol per week, or 76.1 units, about five times the modern recommended limit. In modern terms, the Danish and French mariners would have been consuming the equivalent of 10–13 pints of beer or cider per day, while the English, Swedish, and Spanish were around 6–8 pints per day. Even if we used lower alcohol percentage drinks in our calculations these examples are still far in excess of modern standards for safe drinking.

How would this level of alcohol intake have impacted on the mariners? Were they drunk all the time? Rodger says there is evidence to suggest this was the case. He writes that "It is hardly surprising that there are references to officers 'eternally drunk' in the English navy" (Rodger 1988, 72–73). Drunkenness was clearly a factor in shipboard crime and lack of discipline, but the sailors valued alcohol, and there was "no question of denying the men their liquor" (Rodger 1988, 73; Fury 2012, 217). In general, it takes one hour for the liver to process a pint of alcohol, so if the daily ration was spread over the day this could be metabolized and the acute effects of alcohol consumption could be reduced in the short term. Documentary evidence points to alcohol being the cause of many shipboard accidents (Fury 2012, 217). Long term overuse of alcohol has been linked to a wide range of physical and mental health issues, including liver and heart disease, as well as many types of cancer (Thakker 1998). We cannot be certain about the long term consequences of consuming alcohol at these levels, but we can say that early-modern mariners did consume far in excess of the modern recommended values, and they would have likely suffered health issues in the long term as a result of this.

Alcohol had importance above its nutritional value to mariners. The consumption of alcohol was part of the social system of any ship. The consistently high rations of alcohol suggest that the dulling effects were desired and used as a means to cope with shipboard conditions that were cramped, noisy and monotonous. Alcohol was not only a nutritional item, but a means of escape, entertainment, and distraction for mariners at sea.

Vitamins and minerals

While energy is a basic requirement of any diet, the human body also needs a supply of different minerals and vitamins in order to function correctly and maintain good health in the long term. In each of our examples we calculated the average daily intake of every vitamin and mineral important to maintain good health and compared these to the modern DRV for an adult male from the EFSA.

We found that the daily recommended intake for most inorganic minerals was met by these diets, but there are some discrepancies. The modern PRI for calcium is 1000 mg per day for 18–24-year-old males. The English diet met the modern recommended values on most days, and cheese was the largest contributor of calcium on days it was eaten. Cheese is, in fact, the most calcium dense foodstuff found in any of our examples, with 707 mg of calcium per 100 g. For reasons of preservation, the cheese carried on board ship would have been hard, so a modern equivalent hard cheese was used as standard across every example. Oily fish, such as sardines, anchovies and herring are the next most calcium dense foods we found in ship's diets. The Spanish naval diet from 1560 was on average just slightly below the modern recommended intake value. The Swedish diet was the most lacking, owing to no intake of cheese and a lower beer intake than the other examples. In most cases it was the daily intake of bread and beer that provided the most consistent source of calcium. The wheat and rye flour used in our calculations for bread each have around 30 mg of calcium per 100 g, while beer has a value of 8 mg per 100 g. So, while these foods are much less dense in calcium than cheese, their status as staple foods meant they contributed most of this mineral to the diets. The Danish example did meet the recommended intake, but this was mainly due to the large volume of beer and bread in the supply list. The Danish diet, like that of the Swedish, was lacking in calcium dense foods, such as cheese.

While the majority of mineral needs were met by these diets, there are more glaring omissions in the case of vitamins. All our sixteenth-century examples were far below the recommended daily intake of vitamin D. However, vitamin D can also be produced by the skin when exposed to sunlight, which can eliminate the necessity of dietary intake. So it may be possible that this deficiency had no ill effect (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2016). On the other hand, we could imagine a scenario where sailors might spend a large portion of their time below decks, or in cold climates, away from direct sunlight. In this case, the lack of dietary vitamin D could have an impact on health.

We calculated the nutritional content of the diets of the Mary Rose sailors from 1545 in order to compare the theoretical deficiencies of their diet to the available archeological remains (Coy and Hamilton-Dyer 2005, 604). The Mary Rose diet was lacking in dietary vitamin D and, among the skeletal remains from the ship, several bones showed "evidence for both healed childhood rickets in the bowing of some leg bones, and of the adult form of the disease, osteomalacia" (Fury 2012, 57). Both conditions are caused by a lack of vitamin D. However, we cannot say for certain if ship life caused these conditions, as land populations could also have suffered from a lack of vitamin D, especially in the winter months.

Vitamin C was completely absent from every example diet we examined. None of our official supply lists or rations from any period included a single source of vitamin C. Only anecdotal evidence exists for the exact impact of scurvy on sixteenth century and seventeenth century mariners. The most common condition which develops from the absence of vitamin C in the diet is scurvy. Unlike vitamin D, we must get all vitamin C from our diet (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2013, 2). Scurvy may begin to manifest itself when intake of vitamin C is below intake levels of 10 mg/day (Smolin and Grozvenor 2013). Scurvy occurs in the absence of vitamin C because the protein collagen cannot be synthesized, which eventually leads to defects in the body's connective tissues (Peterkofsky 1991). Early symptoms of scurvy, which include fatigue and mood changes, may have been difficult to identity for early modern mariners (May 2013, 97). The time period in which scurvy develops depends on preexisting levels of vitamin C in the body. The historical evidence suggests that symptoms usually began to manifest after 8–12 weeks at sea (May 2013, 97–98; Phillips 1986, 174).

It is possible that mariners brought their own sources of vitamin C aboard ship and these would obviously not appear in our supply or ration lists. There are references to garlic being included as a condiment aboard Spanish treasure ships (Hamilton 1929; Phillips 1986). Raw garlic contains 17 mg of vitamin C per 100 g. This compares to 36 mg per 100 g of lemon juice. However, garlic never appears in any official ration, so it is difficult to account for the amount consumed or its influence on the health of the mariners, but it is possible that the presence of some garlic helped Spanish mariners avoid scurvy for longer periods. Additionally, scurvy was less of an issue for terrestrial Spanish populations, due to the ready availability of citrus fruits. Only on the longest voyages did the Spanish fleet encounter scurvy.

Despite the similarity in rations, scurvy appears to have been a far greater problem for the fleets of northern Europe, where it was also common during winter for terrestrial populations. Lower levels of preexisting vitamin C in the diet of northern Europeans meant the disease would have a quicker onset than their southern European counterparts.

Accounts normally focus on those voyages that had particularly disastrous results, of which much has been written (Magiorkinis 2011; Phillips 1986, 172–174). In 1593 Richard Hawkins called scurvy "the plague of the Sea, and the spoyle of Mariners" and estimated that over ten thousand men had died from the disease over a twenty-year period in the English fleet (Fury 2012, 210). Before the nineteenth century there are few quantitative figures for the rate of diseases, including scurvy, in the naval fleets. In 1780, Dr James Lind was working at the Royal Hospital at Haslar. Out of 9,787 patients that were admitted in that year 1,457 (14.8%) presented with scurvy, with most suffering from fevers (5,549, 56.6%) (Ellis 1969, 191). So while scurvy was not the most frequent disease encountered by naval doctors, it was still a common problem in the late eighteenth century.

Lind was the physician who had conducted early clinical trials to test the effectiveness of citrus juice as prevention and cure for scurvy in the 1740s. His experiences as a naval surgeon and later as a doctor at Haslar convinced him that orange and lemon juice prevented and cured scurvy. These observations were not immediately implemented by the Admiralty in England, but by 1795 lemon juice was included in English naval ration lists (Baron 2009, 321–324). The impact of this change is evident in figures from mortality figures in the English navy from 1854 to 1855. These figures show no cases of scurvy in these years, with fever remaining and most common illness afflicting seamen (Ellis 1969, 193). The ability of the British to maintain long term and effective blockades during the Napoleonic wars has been attributed to the inclusion of lemon juice in their diet (Baron 2009, 324).

Eighteenth century data from the Danish navy indicate that far fewer deaths occurred from scurvy. A study of medical reports of some 7,000 mariners in the East and West Indies trades concluded that scurvy was a relatively rare phenomenon in trades that were operated by professionals who knew their trade – but it did occur during voyages where captains lost their bearings and were literally at sea for months and months! Contemporary medical assessments of shipboard diseases were that the dominant problem was stomach and digestion problems while problems of malnutrition were relatively infrequent (Gøbel 1979). In this context, the monotonous and salty provisions were likely to blame. However, evidently the absence of vitamin C in the naval diet was a limiting factor and at times had serious military consequences for naval fleets.

Conclusion

The diets of naval mariners in the early modern period were marked by the dual features of stability and limitation. Drying, salting, and alcohol were the main preservative technologies open to medieval and early modern mariners, and consequently food choices were limited. The naval diet of European countries reflected what was already common and available in the nations it originated from but the naval diet was also dictated by preservation and reliability. Items like ship's biscuit were not objects of desire or taste, but a necessity of preservation and energy storage. Its virtual abandonment in the modern day is testament to its taste and overall practicality compared to modern preservation techniques.

Sources of protein were more varied but ultimately relied on the same techniques of preservation, mainly salting and drying. Fish showed the most change over time, and perhaps this is a reflection of a more general change in the status of fish as a commodity from the medieval to modern period (Holm et al. 2019). While fish was rare in medieval fleets of the Mediterranean, it was fairly prominent in all sixteenth century fleets, only to become less prevalent in the eighteenth century. The factors behind this change are unknown but may have been related to both price and durability as food. National and cultural dietary preferences and availability explain differences in diets of different navies. Wine, beer, rye, and wheat stand out as the most distinguishing items, but the basic composition of the naval diet varied little across nations in terms of nutritional quality. There was clearly a difference between a Mediterranean diet of olive oil, wheat and wine, and a Northern diet of beer, fish and rye but the main focus in both diets was on protein, largely derived from meat. All prescribed diets and supplies would have covered the basic energy needs of mariners. In most other areas they were woefully inadequate by modern standards of a "balanced" or "healthy" diet. Volume, access, tradition, and reliability were the driving forces of the naval diet, not nutritional balance or health.

The reconstruction of historical diets is a difficult task. Few sources state exactly what individuals ate on a daily basis. Naval ration and supply lists provide us with some of the best records for estimating the exact consumption of past people. To achieve this, we need to gather precise information about the nutritional value of foods and volumes contained in the diverse range of units we find in historical sources. This paper has attempted to use the most accurate information available in this regard, but inaccuracies undoubtedly remain. The transparent and open database structure used in this research facilitates the re-calculation of our results as better data becomes available. We hope that other researchers can build on the results we have presented here and that experimental archeology and more accurate metrological information can help improve our knowledge about the nutritional intake of mariners in the past.

Notes

1. All figures presented in the charts and tables in this paper were generated from the database (Hayes et al. 2019a).
2. Dietary Reference Values (DRV) is the nutritional requirement system used by the European Food Safety Authority. Given that we employ the EFSA requirements in our analysis we use this term throughout the paper, unless otherwise appropriate. Other institutions and bodies use other measures, such as Recommended Dietary Allowances (RDA), these different systems essentially measure the same thing.
3. One further skeleton was considered a "Juvenile" and one more an "Old Adult."
4. In the English case it is also sometimes referred to as "hard tack."
5. This is the level of nutrient adequate for 97.5% of a given population group (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2017).
6. Muldrew uses the provisions for sailors while in harbor which is why this list is different than our example.
7. Beer, bitter, average (<4% ABV) Comprised of five samples from different brewers; canned, draught, and bottled, including Boddingtons, John Smith, Greene King IPA, Tetley's, and Caffrey's (Finglas et al. 2015).

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Data availability

The data that support the findings of this study are openly available in Figshare.com at http://doi.org/10.6084/m9.figshare.6446345.

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