Diet of New Zealand fur seals (*Arctocephalus forsteri*): a summary

Laura Boren

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ABSTRACT

New Zealand fur seals (*Arctocephalus forsteri*) are increasing in number and expanding to recolonise much of their former range, resulting in a perceived conflict between fur seals and both commercial and recreational fisheries. To assess the level of interaction between fur seals and fisheries, a comprehensive understanding of fur seal diet is needed. This paper summarises what is known about fur seal diet in New Zealand, explains the advantages and disadvantages of various methods for assessing diet, and briefly looks at what information is available from other countries on marine mammal and fisheries interactions. Ten studies on fur seal diet have been carried out in New Zealand. However, most of these have been carried out in the Otago region. Since diet has been shown to vary between locations depending on a number of factors, findings from these studies cannot be applied to the whole of New Zealand. Furthermore, study design and method used to assess diet can greatly affect how data are interpreted and their comparability with other studies. Consequently, more information on fur seal diet is needed to appropriately address the potential for interactions in areas where fur seals have only recently become of increasing concern, and careful consideration needs to be given to study design, the methods employed, and interpretation of the data.

Keywords: New Zealand fur seal, *Arctocephalus forsteri*, diet, commercial fisheries, recreational fisheries, diet analysis methods, interpretation of data

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1. Introduction

As New Zealand fur seals (NZ fur seals; *Arctocephalus forsteri*) continue to recolonise areas of their former range, the likelihood of overlap with fisheries and human activities will continue to increase. Therefore, accurate assessment of their diet and foraging habits will be important for enabling concerns to be addressed as they arise.

This article summarises what is currently known about the diet and foraging locations of NZ fur seals in the New Zealand region. It is separated into four main sections:

- Diet
- Methods for assessing diet
- Foraging locations
- What has been learned from other countries

A list of further reading is also included, for expansion of the subject to other regions and species.

2. Diet

Data on NZ fur seal diet have been obtained from multiple sites within six high-level districts. Otago is the most studied district, involving studies in 1964 and 1981, and three in the 1990s (Street 1964; Tate 1981; Dickson 1996; Fea et al. 1999; Harcourt et al. 2002). Further work in 1996 and 1997 in Southland and Fiordland identified 18 new prey taxa not previously reported in the diet of NZ fur seals (Holborow 1999). One additional study was undertaken in the 1990s at two sites in Westland and one site on the Kaikoura coast (Carey 1992), and one study was carried out in Cook Strait (Dix 1993). More recently, work was carried out at Tonga Island in the Nelson/Marlborough region (Willis et al. 2008) and a study began on Banks Peninsula in January 2008 and is ongoing (F. Maddigan and L. Allum, Department of Conservation, Mahaanui Area Office and Canterbury Conservancy, unpubl. data).

Table 1 shows the major species found in the diet of NZ fur seals in each district. It also indicates whether the diet has been examined for all seasons, breeding and non-breeding sites, and age/sex groups, as each of these can influence diet in this species. Species codes are listed in Appendix 1. A wide range of species have been documented in the diet of fur seals; however, only squid and octopus were consistently found in all studies. Various species of lanternfish were found in fur seal diet samples at all locations except Tonga Island, where shallow water, schooling species such as anchovy and pilchard were more dominant. Jack mackerel, baracouta, hoki, red cod and ahuru (or pink cod) were also commonly reported.

TABLE 1. THE DIET OF NEW ZEALAND FUR SEALS (*Arctocephalus forsteri*) SUMMARISED FROM TEN STUDIES.
Indication is given of whether the studies included all seasons, both breeding and non-breeding sites, and all age groups. '?' is used in cases where studies did not specify whether sites were breeding sites or not. 'Major' species are those that made up the five most dominant species by either weight or number. While smaller fish such as lantern fish were often numerically dominant, they were not always dominant by mass; therefore, there are occurrences where there are more than five species listed as being major.

DISTRICT	DIET		STUDY CONDUCTED FOR A FULL YEAR?	STUDY INCORPORATED BREEDING AND NON-BREEDING SITES?	ALL AGE GROUPS STUDIED?	REFERENCE
North Island	Major:	SYM, HOK, JMA, DSS, SQ	N	Y	N	Dix 1993
	Minor:	LHE, RCO, SHA, BIRD				
Nelson/ Marlborough: Kaikoura	Major:	SYM, HOK, LHE, BAR, SQU, OCT	N	N	N	Street 1963 Carey 1992
Nelson/ Marlborough: Tonga Island	Major:	ANC, PIL, SQU, JMA, SPR				Willis et al. 2008
	Minor:	GMU, SSI, OCT, OPA, WIT, STY				
Canterbury	Species recorded*:	SQU, SYM, LHE, BAR, OCT, PCO, RCO	N	N	N	Street 1964 Maddigan and Allum (unpubl. data)
West Coast (South Island)	Major:	SQU, OCT, LAN (4 spp.), ANC, HOK, PCO	N	?	N	Carey 1992 Holborow 1999
	Minor:	HAG, SPL, RAT, JMA, DOR, YEM, DSS, RHY, JAV, WWA, SWA				
Otago	Major:	SQU, LAN (6 spp.), PCO, OCT, JMA, RCO, BAR, HOK, SPR	Y	Y	N	Street 1964 Tate 1981 Dickson 1996 Fea et al. 1999 Harcourt et al. 2002
	Minor:	SIL, LAM, WSQ, WWA, YEM, TAR, FRO, BCO, OPA, GUD, LSO, GST, SOL, FLO, SPD, RAT				
Southland	Major:	SQU, OCT, LAN, RCO, HOK, SPR, JMA, BAR	Y	Y (Snares non-breeding, remainder breeding)	N	Holborow 1999
	Minor:	SPD, SCH, RAT, RBT, YCO, SBW, JAV, DSS, SPE, TSQ, DCO, SWA, COL				

* Note that full analysis of the dominance of prey species was not undertaken for the Canterbury study, so species are simply listed in order of numerical dominance.

3. Methods for assessing diet

Several methods are available for assessing diet, all of which require some level of prior knowledge about the possible prey species before any conclusions can be made (e.g. otolith library, DNA sequences, fatty acid signature). The main methods are summarised below, with a more detailed assessment of all methods provided in Table 2.

Stomach content analysis

The advantage of this method is that prey can be identified to species level and the direct or indirect consumption of prey can be confirmed. However, it requires that animals be euthanized. As an alternative to lethal sampling, freshly stranded animals can be sampled. However, many of their stomachs will be empty, and sample sizes are usually small.

Scat analysis

This technique is less invasive than stomach content analysis, and yields larger sample sizes and allows prey to be identified to species level. However, the importance of larger prey items is often underestimated due to differential prey digestion and retention, and direct or indirect consumption may be difficult to determine.

Regurgitates analysis

Like scat analysis, this technique is less invasive than stomach content analysis, and yields larger sample sizes and allows prey to be identified to species level. However, regurgitates only occur seasonally, with substantially fewer regurgitates available in winter as a result of the life cycle of arrow squid—as the abundance of squid decreases in winter, fur seals tend to forage more generally (Tate 1981; Fea et al. 1999; Harcourt et al. 2002). Regurgitates also tend to represent large prey items and cephalopods, which are not as easily digestible.

Fatty acid signature analysis (FASA)

This method provides a longer term assessment of diet and can be used to detect changes in diet composition. However, prey size cannot be estimated and identification to species level is only possible if the FASA of the prey species is known. This technique has not been used on NZ fur seals, so a baseline study would be required to validate it.

Stable isotope analysis (SIA)

This is a useful technique for detecting changes in diet composition over time. It can also be used to indicate what trophic level a species feeds at and, potentially, rough foraging locations. However, prey cannot be identified to species level. This method has not been used on NZ fur seals, so a baseline study would be required to validate it.

TABLE 2. DETAILED COMPARISON OF METHODS USED TO ASSESS DIET IN MARINE MAMMALS (ADAPTED FROM TOLLIT ET AL. 2006).
Aspects deemed 'possible' are possible in theory but require further development of the method, etc.

METHOD	INVASIVENESS	COST/ EFFORT	SAMPLE SIZE	TIMEFRAME	IDENTIFICATION OF SPECIES	PREY SIZE ESTIMATE	DIRECT CONSUMPTION OF PREY DETECTED?	ABILITY TO INFER FORAGING LOCATION	ADDITIONAL POINTS SPECIFIC TO METHODS
Stomach contents	Extreme	Minimal–moderate	Low	Short	Yes	Yes	Yes	Minimal	Differential prey digestion and retention affects results. Empty stomachs can reduce sample size.
Scat (hard parts)	None–moderate	Minimal	Moderate–high	Short	Yes	Yes	No	Minimal	Differential prey digestion and retention affects results. Underestimates importance of large prey.
Regurgitate (hard parts)	None–moderate	Minimal	Low–moderate	Short	Yes	Yes	No	Very low	Seasonal, and only representative of large prey and cephalopods. Differential prey digestion and retention affects results.
Scat (DNA)	None–moderate	Moderate	Moderate–high	Short	Yes	No	No	Minimal	New technique, relatively untested. Requires knowledge of DNA of many prey items.
Lavage (enema)	Moderate	Moderate –high	Low	Short	Yes	Yes	Possible	Minimal	Differential prey digestion and retention affects results. Empty stomachs can reduce sample size.
Stable isotopes	Moderate (depends on tissue used)	Moderate	Moderate (depends on tissue used)	Moderate–long	No	No	No	Yes	Only allows trophic level quantification. Can detect changes in diet over time. Requires a priori knowledge of prey isotopes. Requires comparison with other methods.
Fatty acid signature (FAS)	Moderate	Moderate–high	Moderate	Moderate–long	Possible	No	No	Minimal	New technique, relatively untested. Requires a priori knowledge of prey FAS.
Head camera	Moderate	High	Low	Short	Possible	Possible	Possible	Yes	Requires retrieval of equipment. Few feeding bouts actually captured.
Direct observation	Minimal	High	Low	Immediate	Possible	Possible	Possible	Possible	Limited to prey brought to surface, and usually to near-shore interactions.
Acoustic sonar array	Minimal	High	Low–moderate	Immediate	Possible	Possible	Possible	Possible	Requires a priori knowledge of feeding habits or likely feeding grounds, or the ability to follow animals to feeding grounds. Requires a priori knowledge of prey acoustic signature.

Methods employed in New Zealand

The only methods employed for studying NZ fur seal diet have been stomach content analysis, and hard part analysis from scat and regurgitates. Table 3 shows the methods used and sample sizes collected for each of the districts.

Interpreting results

Since each method is likely to yield different results due to the respective biases outlined above, studies utilising different methods will not be comparable. Also, a study that only incorporates one method will not be as accurate a representation of diet as a study that incorporates multiple methods. To minimise bias in a study, it is important to carefully consider the study design (e.g. what samples were collected where, and when and how they were analysed), and to be aware of a method's limitations when interpreting the data. For example, scats and regurgitates may be biased towards feeding that has taken place closer to shore at the end of a foraging trip, due to digestion times and the fact that animals will have defecated at sea. Scats are also likely to be biased against larger prey species, or any prey item where the head is not ingested. Additionally, whether data were presented using numerical dominance of prey or proportion of biomass can lead to invalid inferences about fur seal diet. Thus, the different methods used (Table 2) and study designs (Table 1) make it difficult to compare NZ fur seal diet between studies and locations.

TABLE 3. THE NUMBER OF SITES STUDIED WITHIN EACH HIGH-LEVEL DISTRICT, THE METHODS EMPLOYED AT EACH SITE, AND THE NUMBER OF SAMPLES COLLECTED FOR EACH METHOD IN THE ENTIRE DISTRICT.

DISTRICT	NUMBER OF SITES	METHOD	SAMPLE SIZE	REFERENCE
North Island	5	Scats	245	Dix 1993
		Regurgitates	12	
Nelson/	2	Stomach contents	9	Street 1963
Marlborough		Scats	286*, 133	Carey 1992; Willis et al. 2008
		Regurgitates	15	Willis et al. 2008
Canterbury	3	Stomach contents	2	Street 1964
		Scats	88	Maddigan and Allum
		Regurgitates	8	(unpubl. data)
West Coast	3	Scats	286*	Carey 1992
South Island		Scats and regurgitates	114†	Holborow 1999
Otago	6	Stomach contents	32	Street 1964
		Scats	1591	Tate 1981
		Regurgitates	674	Dickson 1996
				Fea et al. 1999
				Harcourt et al. 2002
Southland	5	Stomach contents	27	Holborow 1999
		Scats and regurgitates	516†	

* Sample size of 286 given for entire study, not broken down by region.

† Sample size breakdown by region did not distinguish between the two methods used.

4. Foraging locations

Obtaining information on where NZ fur seals forage requires costly equipment and a significant amount of field effort. Consequently, studies of foraging locations have focused primarily on females, as they are easier to study than males.

The information available for New Zealand is mostly from Otago (Harcourt et al. 1995, 2001, 2002), with one additional study from Open Bay Islands, West Coast (Mattlin et al. 1998). Female NZ fur seals in Otago were shown to forage close to the continental slope (70–80 km from the rookery) in summer, and further away in autumn (178 km) and winter (162 km). On the West Coast, females foraged within the 500-m depth contour, usually remaining within 250 km of the rookery. While some information can be inferred for other colonies based on geography, bathymetry and what we know about fur seals elsewhere (Bradshaw et al. 2002), this cannot confirm where NZ fur seals are actually foraging. Colonies around New Zealand are exposed to a variety of terrain types and oceanographic influences, meaning that foraging locations and diet are likely to vary a great deal around the country. Therefore, studies are needed at a variety of different locations around the country encompassing a range of environmental variables.

5. What has been learned from other countries?

Marine food webs are incredibly complex, and the removal of one species can have dramatic effects on other species. This was illustrated by the findings from a South African study (Punt & Butterworth 1995), which was undertaken following calls to cull Cape fur seals (*A. pusillus pusillus*) because of the belief they preyed heavily on two species of commercially harvested hake (*Merluccius* spp.). The goal of the study was to determine the interaction between the fur seals and their prey, to determine if a cull would be beneficial to the sustainability of the fishery. It was found that fur seals did not forage equally on the two species of hake (*M. capensis and M. paradoxus*). In fact, they preyed preferentially on the species that in turn foraged on the more commercially desirable hake. Therefore, a cull on fur seals would have had negative effects on the fishery.

Other studies elsewhere have also assessed the level of prey consumption by marine mammals, and the potential overlap with commercial and/or recreational fisheries (Yodzis 2001; David & Wickens 2003; Goldsworthy et al. 2003; Lavigne 2003). However, in order to adequately model this consumption and potential overlap, information on diet, foraging behaviour, foraging location, population/colony size, colony dynamics, and body size is required. While knowing the prey species of fur seals may indicate the environment in which they are foraging, it is impossible to determine the extent, if any, of spatial overlap with a fishery without the combined information from satellite tracking and direct observation.

As the NZ fur seal populations are growing, there is an increased concern about the potential for competition with various commercial (e.g. West Coast South Island hoki) and recreational (e.g. Marlborough Sounds blue cod) fisheries, and there is an increasing occurrence of fur seal bycatch in various offshore trawl fisheries (Cawthorn & Wells 2008).

6. Conclusions and recommendations

The ten studies on NZ fur seal diet carried out to date show that this species feeds on a wide range of prey, with the Otago and Southland populations showing the widest range (see Table 1). Some of the prey species recorded are commercially valuable, particularly offshore species like hoki, arrow squid, red cod and jack mackerel. Some small schooling fish commonly used for bait by recreational fishers were also reported, including anchovies, pilchards and sprats. However, these species were only reported in reasonable quantities in one study (Willis et al. 2008), where the colony was in relatively shallow water and at least 230 km from the 1000-m contour. All of the remaining study colonies had reasonable access to deeper water and the ability to forage within the 500-m and 1000-m depth contours (< 150 km to 1000-m contour) (distances from NABIS; www.nabis.co.nz). Therefore, while fur seals tend to feed on offshore species, they may feed more on schooling fish when living in shallow water environments. There was no significant evidence that they feed on inshore fish commonly targeted by inshore recreational or commercial fishers. Another key finding of this review is that several species of lanternfish (myctophids) were observed in fur seal diet at all locations except the shallow water colony of Abel Tasman. These are small, very oily, deep sea fish that are not commercially desirable.

Studies in New Zealand and other countries have shown that the diet of fur seals depends on a considerable number of factors. These include season, sex of the animal sampled, whether the individual is breeding or non-breeding, the local oceanography and bathymetry surrounding the colony, and climatic patterns at the time (e.g. El Niño Southern Oscillation). Additionally, the method used to assess diet can bias the results in different ways, depending on the relative benefits and limitations (Table 2). Because of the high amount of variation in fur seal diet, and the fact that different assay methods may produce different results, it is imperative that results are interpreted with caution. Direct comparisons between studies are not always feasible because of these same issues.

As the fur seal population continues to grow within New Zealand, the potential for overlap with humans and fisheries is increasing. Therefore, further study of fur seal diet is recommended. In particular, validation studies on the use of FASA and SIA should be initiated, as these methods, in conjunction with more traditional methods, may provide a more accurate picture of fur seal diet around the country. In the past, study sites were primarily selected based on logistics, access and the availability of resources, leading to the vast majority of studies occurring in one region. In the future, effort should instead be focused on areas where there is considerable overlap between fur seal and human populations or fishing activities, e.g. Kaikoura, Marlborough Sounds and the West Coast of the South Island. These studies should incorporate a range of methods, the full range of seasons and, where possible, samples from breeding and non-breeding sites. Where it is not feasible to collect samples from a wide range of conditions, this needs to be clearly indicated and taken into account during interpretation. Data should also be presented using both numerical dominance of prey and proportion of biomass, as this will give a better indication of the relative importance of large and small prey species in the diet.

For conservation and management purposes, a broader understanding of fur seal diet is needed and targeted science in locations of concern would be advised. With this information, government departments would be better placed to respond to the myriad of questions and concerns that are raised about fur seals and fisheries in New Zealand.

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Appendix 1

SPECIES CODES OF PREY ITEMS

SPECIES CODE	COMMON NAME	SCIENTIFIC NAME
ANC	Anchovy	*Engraulis australis*
BAR	Barracouta	*Thyrsites atun*
BCO	Blue cod	*Parapercis colias*
BIRD	Unidentified sea birds	
COL	Oliver's rattail	*Caelorinchus oliverianus*
DCO	Dwarf cod	*Notophycis marginata*
DOR	Dory	*Zeidae*
DSS	Deepsea smelt	*Bathylagus* spp.
ELT	Lanternfish: Electrona	*Electrona* spp.
FLO	Flounder	*Paralichthys*
FRO	Frostfish	*Lepidopus caudatus*
GIL	Triple fin	*Cryptichthys jojettae*
GMU	Grey mullet	*Mugil cephalus*
GST	Lightfish	*Gonostomatidae*
GUD	Graham's gudgeon	*Grahamichthys radiata*
GYM	Lanternfish: Gymnoscopelus	*Gymnoscopelus* spp.
HAG	Hagfish	*Eptatretus cirrhatus*
HOK	Hoki	*Macruronus novaezelandiae*
JAV	Javelin fish	*Lepidorhynchus denticulatus*
JMA	Jack mackerel	*Trachurus declivis*
LAM	Lamprey	*Geotria australis*
LAN	Lanternfish	*Myctophidae*
LHE	Lanternfish: Lampanyctodes	*Lampanyctodes hectoris*
LSO	Lemon sole	*Pelotretis flavilatus*
OCT	New Zealand octopus	*Octopus maorum*
OPA	Opalfish	*Hemerocoetes* spp.
PCO	Ahuru	*Auchenoceros punctatus*
PIL	Pilchard	*Sardinops neopilchardus*
RAT	Rattail	*Macrouridae*
RBT	Redbait	*Emmelichthys nitidus*
RCO	Red cod	*Pseudophycis bachus*
RHY	Common roughy	*Paratrachichthys trailli*
SBW	Southern blue whiting	*Micromesistius australis*
SCH	School shark	*Galeorhinus galeus*
SHA	Unidentified shark	
SOL	Sole	*Peltorhamphus* spp.
SPD	Spiny dogfish	*Squalus acanthias*
SPE	Seaperch	*Helicolenus* sp.
SPL	Waryfish	*Scopelosaurus* spp.
SPR	Sprat	*Sprattus antipodum*
SQU	Arrow squid	*Nototodarus sloanii*
SQX	Unidentified squid	
SSI	Silverside	*Argentina elongata*
STY	Spotty	*Notolabrus celidotus*
SWA	Silver warehou	*Seriolella punctata*

Continued on next page

Appendix 1—continued

SPECIES CODE	COMMON NAME	SCIENTIFIC NAME
SYM	Lanternfish: Symbolophorus	*Symbolophorus* spp.
TAR	Tarakihi	*Nemadactylus macropterus*
TSQ	Antarctic flying squid	*Todarodes filippovae*
WIT	Witch	*Arnoglossus scapha*
WSQ	Warty squid	*Moroteuthis ingens*
WWA	Warehou	*Seriolella caerulea*
YCO	Yellow weever	*Parapercis gilliesi*
YEM	Yelloweyed mullet	*Aldrichetta forsteri*

Appendix 2

COMPENDIUM OF THE DATA COLLECTED ON DIET OF THE NEW ZEALAND FUR SEAL FROM TEN STUDIES

NS = not specified. Vomits are regurgitates. Seasons are: S = summer, A = autumn, W = winter, Spr = spring. See Appendix 1 for explanation of species codes.

LOCATION	YEAR	METHOD USED (SAMPLE SIZE)	SEASON (NUMBER OF MONTHS)	BREEDING OR NON-BREEDING	SEX STUDIED	PRIMARY SPECIES TAKEN	REFERENCES
Kaikoura	1. 1960s	1. Stomach (9)	1. NS	1. NS	1. NS	1. BAR	1. Street 1964
	2. 1991	2. Scats (286*)	2. A,W (5)	2. NS	2. NS	2. SYM	2. Carey 1992
Cape Foulwind	2. 1991	2. Scats (*)	2. S, A, W (7)	2. NS	2. NS	2. ANC	2. Carey 1992
Gillespies Beach	2. 1991	2. Scats (*)	2. S, A, W (5)	2. NS	2. NS	2. PCO	2. Carey 1992
Open Bay Islands	2. 1991	2. Scats (*)	2. A (1)	2. Breeding	2. NS	2. LHE	2. Carey 1992
Otago	1. 1960s	1. Stomach contents (32)	1. NS	1. NS	1. NS	1. BAR	1. Street 1964
	3. 1981	3. Vomits (334), scats (69)	3. S, A, W (6)	3. Non-breeding	3. NS	3. SQU	3. Tate 1981
	4. 1995	4. Scats (332), vomits (90)	4. S, A, W (6)	4. Breeding	4. NS	4. SQU	4. Dickson 1996
	5. 1993/94	5. Scats (500), vomits (84)	5. Full year (13)	5. Breeding	5. NS	5. SQU	5. Fea et al. 1999
	6. 1994/95	6. Scats (690), vomits (166)	6. S, A, W (NS)	6. Breeding	6. NS	6. SQU	6. Harcourt et al. 2002
Cook Strait	7. 1991/1992	7. Scats (246), regurgitates (12)	7. 1991: W, Spr (5)	7. Breeding (1) and non-breeding (4)	7. NS	7. HOK (present in more samples) SYM (numerically dominant)	7. Dix 1993
Fiordland	8. 1996/97	8. Scats and vomits (114)	8. All seasons	8. Breeding	8. NS	8. SQU, LAN	8. Holborow 1999
Foveaux Strait	1. 1960s	1. Stomach contents (13)	1. NS	1. NS	1. NS	1. Bench Island—SQ	1. Street 1964
	8. 1995–97	8. Scats and vomits (416)	8. All seasons	8. Breeding (3)	8. NS	8. SQU, LAN	8. Holborow 1999
Nugget Point	1. 1960s	1. Stomach contents (14)	1. NS	1. NS	1. NS	1. Nugget Point—BAR	1. Street 1964
Snares Islands	8. 1996/97	8. Scats and vomits (104)	8. All seasons	8. Non-breeding	8. NS	8. SQU, BAR	8. Holborow 1999
Banks Peninsula	1. 1960s	1. Stomach contents (2)	1. NS	1. NS	1. NS	1. Some BAR bones	1. Street 1964
	9. 2007	9. Scats (88), vomits (8)	9. S (2)	9. Breeding	9. NS	9. LAN, SQU	9. Maddigan and Allum (unpubl. data)
Abel Tasman	10. 2007	10. Scats (133), vomits (15)	10. Spr, A (2)	10. Breeding	10. Not analysed	10. SQU, PIL, ANC	10. Willis et al. 2008

* Sample size of 286 given for entire study, not broken down by region.

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