Food insecurity is closely tied to poverty; globally about 25 to 30% of poor people, measured using a US$1 to US$2 per day standard, live in urban areas (Ravallion et al., 2007; IFAD, 2010). Most poor countries have a larger fraction of people living in rural areas and poverty rates tend to be higher in rural settings (by slight margins in South Asia and Africa, and by large margins in China). In Latin America, poverty is more skewed to urban areas, with roughly two-thirds of the poor in urban areas, a proportion that has been growing in the past decade (*medium evidence*, *medium agreement*). Rural areas will continue to have the majority of poor people for at least the next few decades, even as population growth is higher in urban areas (*medium evidence*, *medium agreement*) (Ravallion et al., 2007; IFAD, 2010).

The effects of price volatility are distinct from the effects of gradual price rises, for two main reasons. First, rapid shifts make it difficult for the poor to adjust their activities to favor producing higher value items. Second, increased volatility leads to greater uncertainty about the future and can dampen willingness to invest scarce resources into productivity enhancing assets, such as fertilizer purchases in the case of farmers or rural infrastructure in the case of governments. Several factors have been found to contribute to increased price volatility: poorly articulated local markets, increased incidence of adverse weather events, and greater reliance on production areas with high exposure to such risks, biofuel mandates, and increased links between energy and agricultural markets (World Bank, 2012). Vulnerability to food price volatility depends on the degree to which households and countries are net food purchasers; the level of integration into global, regional, and local markets; and their relative degree of volatility, which in turn is conditional on their respective governance (*robust evidence*, *medium agreement*) (HLPE, 2011; World Bank, 2012).

7.1.3. Summary from AR4

Food systems as integrated drivers, activities, and outcomes for food security did not feature strongly in AR4. Summary points from AR4 were that, with *medium confidence*, in mid- to high-latitude regions moderate warming will raise crop and pasture yields. Sight warming will decrease yields in low-latitude regions. Extreme climate and weather events will, with *high confidence*, reduce food production. The benefits of adaptation vary with crops and across regions and temperature changes; however, on average, they provide approximately a 10% yield benefit when compared with yields when no adaptation is used (WGII AR4 Section 5.5.1). Adaptive capacity is projected to be exceeded in low-latitude areas with temperature increases of more than 3°C. Local extinctions of particular fish species are expected at the edges of their ranges (*high confidence*) and have serious negative impacts on fisheries (*medium confidence*).

7.2. Observed Impacts, with Detection and Attribution

7.2.1. Food Production Systems

Formal detection of impacts requires that observed changes be compared to a clearly specified baseline that characterizes behavior in the absence of climate change (Chapter 18). For food production systems, the number and strength of non-climate drivers, such as cultivar improvement or increased use of irrigation and fertilizers in the case of crops, make defining a clear baseline extremely difficult. Most non-climatic factors are not very well characterized in terms of spatial and temporal distributions, and the relationships between these factors and specific outcomes of interest (e.g., crop or fish production) are often difficult to quantify.

Attribution of any observed changes to climate trends are further complicated by the fact that models linking climate and agriculture must, implicitly or explicitly, make assumptions about farmer behavior. In most cases, models implicitly assume that farming practices or technologies did not adjust in response to climate over the period of interest. This assumption can be defended in some cases based on ancillary data on practices, or based on small differences between using models with and without adaptation (Schlenker and Roberts, 2009). However, in some instances the relationship between climate conditions and crop production has been shown to change over time because of management changes, such as introduction of irrigation or changes in crop varieties (Zhang et al, 2008; Liu et al., 2009; Sakurai et al., 2012).

7.2.1.1. Crop Production

Many studies of cropping systems have estimated impacts of observed climate changes on crop yields over the past half century, although they typically do not attempt to compare observed yields to a counterfactual baseline, and thus are not formal detection and attribution studies. These studies employ both mechanistic and statistical approaches (Section 7.3.1), and estimate impacts by running the models with observed historical climate and then computing trends in modeled outcomes. Based on these studies, there is *medium confidence* that climate trends have negatively affected wheat and maize production for many regions (Figure 7-2) (*medium evidence*, *high agreement*). Because many of these regional studies are for major producers, and a global study (Lobell et al., 2011a) estimated negative impacts on these crops, there is also *medium confidence* for negative impacts on global aggregate production of wheat and maize. Effects on rice and soybean yields have been small in major production regions and globally (Figure 7-2) (*medium evidence*, *high agreement*). There is also *high confidence* that warming has benefitted crop production in some high-latitude regions, such as northeast China or the UK (Jaggard et al., 2007; Chen et al., 2010; Supit et al., 2010; Gregory and Marshall, 2012).

More difficult to quantify with models is the impact of very extreme events on cropping systems, as by definition these occur very rarely and models cannot be adequately calibrated and tested. Table 18-3 lists some notable extremes over the past decade, and the impacts on cropping systems. Despite the difficulty of modeling the impacts of these events, they clearly have sizable impacts (Sanchez et al. 2014) that are apparent immediately or soon after the event, and therefore not easily confused with effects of more slowly moving factors. For a subset of these events, climate research has evaluated whether anthropogenic activity has increased or decreased their likelihood (Table 18-3).

A sizable fraction of crop modeling studies were concerned with production for individual sites or provinces, spatial scales below which

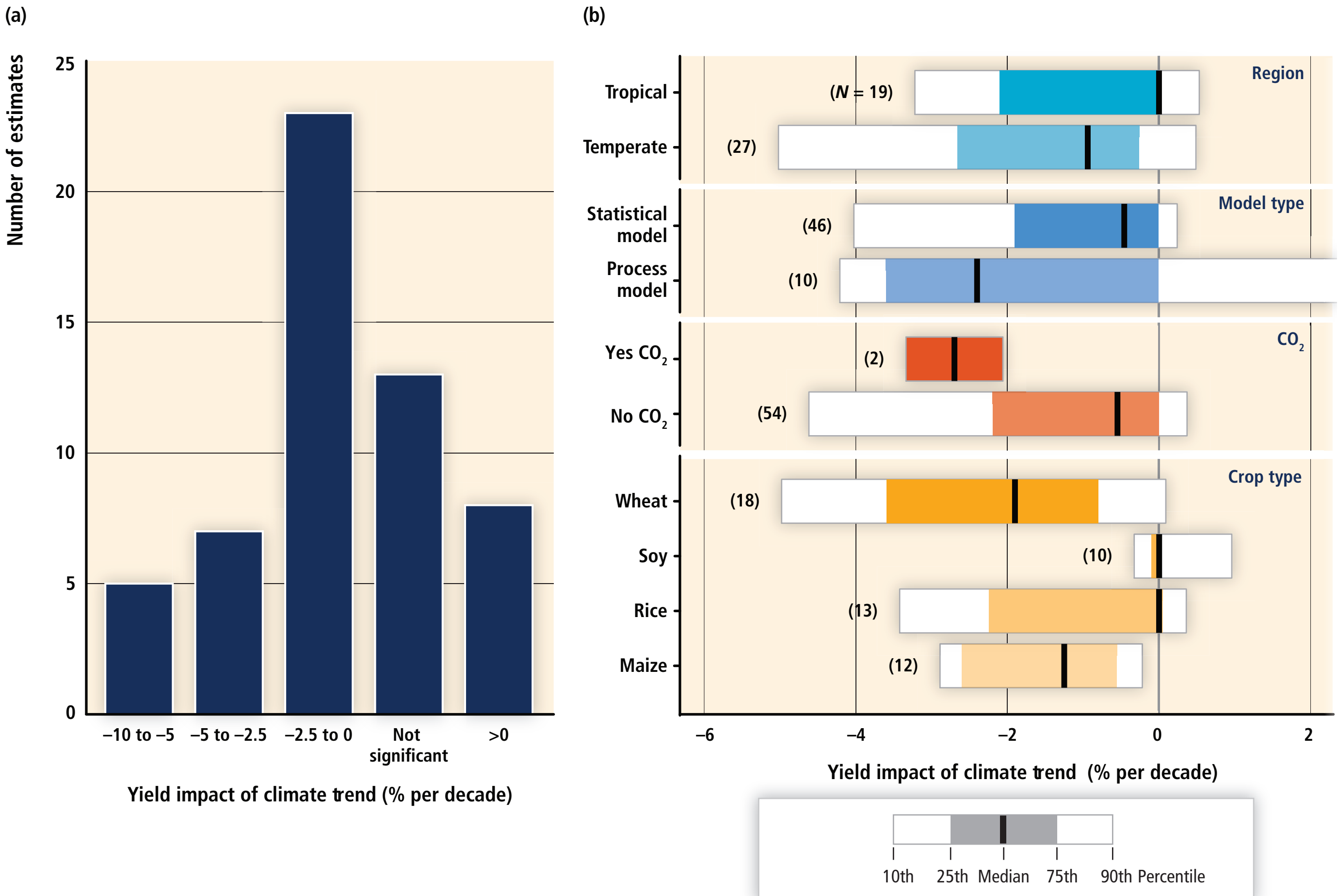

Figure 7-2 | Summary of estimates of the impact of recent climate trends on yields for four major crops. Studies were taken from the peer-reviewed literature and used different methods (i.e., physiological process-based crop models or statistical models), spatial scales (stations, provinces, countries, or global), and time periods (median length of 29 years). Some included effects of positive carbon dioxide (CO_2) trends (Section 7.3.2.1.2) but most did not. (a) Number of estimates with different level of impact (% yield per decade). (b) Boxplot of estimates separated by temperate vs. tropical regions, modeling approach (process-based vs. statistical), whether CO_2 effects were included, and crop. Boxplots indicate the median (vertical line), 25th to 75th percentiles (colored box), and 10th to 90th percentiles (white box) for estimated impacts in each category, and numbers in parentheses indicate the number of estimates. Studies were for China (Tao et al., 2006, 2008a, 2012; Wang et al., 2008; You et al., 2009; Chen et al., 2010), India (Pathak et al., 2003; Auffhammer et al., 2012), USA (Kucharik and Serbin, 2008), Mexico (Lobell et al., 2005), France (Brisson et al., 2010; Licker et al., 2013), Scotland (Gregory and Marshall, 2012), Australia (Ludwig et al., 2009), Russia (Licker et al., 2013), and some studies for multiple countries or global aggregates (Lobell and Field, 2007; Welch et al., 2010; Lobell et al., 2011a). Values from all studies were converted to percentage yield change per decade. Each study received equal weighting as insufficient information was available to judge the uncertainties of each estimate.

the changes in climate conditions are attributable to anthropogenic activity (WGI AR5 Chapter 10). Similarly, most crop studies have focused on the past few decades, a time scale shorter than most attribution studies for climate. However, some focused on continental or global scales (Lobell and Field, 2007; You et al., 2009; Lobell et al., 2011a), at which trends in several climatic variables, including average summer temperatures, have been attributed to anthropogenic activity. In particular, global temperature trends over the past few decades are attributable to human activity (WGI AR5 Chapter 10), and the studies discussed above indicate that this warming has had significant impacts on global yield trends of some crops.

In general, little work in food production or food security research has focused on determining whether climate trends affecting agriculture can be attributed to anthropogenic influence on the climate system. However, as the field of climate detection and attribution proceeds to finer spatial and temporal scales, and as agricultural modeling studies expand to broader scales, there should be many opportunities to link climate and crop studies in the next few years. Importantly, climate attribution is increasingly documented not only for measures of average conditions over growing seasons, but also for extremes. For instance, Min et al. (2011) attributed changes in rainfall extremes for 1951–1999 to anthropogenic activity, and these are widely acknowledged as important to cropping systems (Rosenzweig et al., 2002). Frost damage is an important constraint on crop growth in many crops, including for various high-value crops, and significant reductions in frost occurrence since 1961 have been observed and attributed to greenhouse gas (GHG) emissions in nearly every region of the world (Zwiers et al., 2011; IPCC, 2012).

Increased frequency of unusually hot nights since 1961 are also attributable to human activity in most regions (WGI AR5 Chapter 10). These events are damaging to most crops, an effect that has been observed most commonly for rice yields (Peng et al., 2004; Wassmann et al., 2009; Welch et al., 2010) as well as rice quality (Okada et al., 2011). Extremely high daytime temperatures are also damaging and occasionally lethal to crops (Porter and Gawith, 1999; Schlenker and Roberts, 2009), and trends at the global scale in annual maximum daytime temperatures since 1961 have been attributed to GHG emissions (Zwiers et al., 2011). At regional and local scales, however, trends in daytime maximum are harder to attribute to GHG emissions because of the prominent role of soil moisture and clouds in driving these trends (Christidis et al., 2005; Zwiers et al., 2011).

In addition to effects of changes in climatic conditions, there are clear effects of changes in atmospheric composition on crops. Increase of atmospheric CO_2 by greater than 100 ppm since preindustrial times has *virtually certainly* enhanced water use efficiency and yields, especially for C_3 crops such as wheat and rice, although these benefits played a minor role in driving overall yield trends (Amthor, 2001; McGrath and Lobell, 2011).

Emissions of CO_2 often are accompanied by ozone (O_3) precursors that have driven a rise in tropospheric O_3 that harms crop yields (Morgan et al., 2006; Mills et al., 2007; Section 7.3.2.1.2). Elevated O_3 since preindustrial times has *very likely* suppressed global production of major crops compared to what they would have been without O_3 increases, with estimated losses of roughly 10% for wheat and soybean and 3 to 5% for maize and rice (Van Dingenen et al., 2009). Impacts are most severe over India and China (Van Dingenen et al., 2009; Avnery et al. 2011a,b), but are also evident for soybean and maize in the USA (Fishman et al., 2010).

7.2.1.2. Fisheries Production

The global average consumption of fish and other products from fisheries and aquaculture in 2010 was 18.6 kg per person per year, derived from a total production of 148.5 million tonnes, of which 86% was used for direct human consumption. The total production arose from contributions of 77.4 and 11.2 million tonnes respectively from marine and inland capture fisheries, and 18.1 and 41.7 million tonnes respectively from marine and freshwater aquaculture (FAO, 2012). Fisheries make particular contributions to food security and more than 90% of the people engaged in the sector are employed in small-scale fisheries, many of whom are found in the poorer countries of the world (Cochrane et al., 2011). The detection and attribution of impacts are as confounded in inland and marine fisheries as in terrestrial food production systems. Overfishing, habitat modification, pollution, and interannual to decadal climate variability can all have impacts that are difficult to separate from those directly attributable to climate change.

One of the best studied areas is the Northeast Atlantic, where the temperature has increased rapidly in recent decades, associated with a poleward shift in distribution of fish (Perry et al., 2005; Brander, 2007; Cheung et al., 2010, 2013). There is *high confidence* in observations of increasing abundance of fish species in the northern extent of their ranges while decreases in abundance have occurred in the southern part (Section 30.5.1.1.1). These trends will have mixed implications for fisheries and aquaculture with some commercial species negatively and others positively affected (Cook and Heath, 2005). There is a similar well-documented example in the oceans off southeast Australia with large warming trends associated with more southward incursion of the Eastern Australian Current, resulting in southward migration of marine species into the oceans around eastern Tasmania (*robust evidence*, *high agreement*; Last et al., 2011).

As a further example, coral reef ecosystems provide food and other resources to more than 500 million people and with an annual value of US$5 billion or more (Munday et al., 2008; Hoegh-Guldberg, 2011). More than 60% of coral reefs are considered to be under immediate threat of damage from a range of local threats, of which overfishing is the most serious (Burke et al., 2011; see also Box CC-CR) and the percentage under threat rises to approximately 75% when the effect of rising ocean temperatures is added to these local impacts (Burke et al., 2011). Wilson et al. (2006) demonstrated that declines in coral reef cover typically led to declines in abundance of the majority of fish species associated with coral reefs. There is *high confidence* that the availability of fish and invertebrate species associated with coral reefs that are important in many tropical coastal fisheries is *very likely* to be reduced (Section 30.6.2.1.2). Other examples around the world are described in Section 30.5.1.1.1.

These changes are impacting marine fisheries: a recent study that examined the composition of global fisheries catches according to the inferred temperature preferences of the species caught in fisheries found that there had been changes in the species composition of marine capture fisheries catches and that these were significantly related to changes in ocean temperatures (Cheung et al. 2013; Section 6.4.1.1). These authors noted that the relative contribution to catches by warmer water species had increased at higher latitudes while the contributions of subtropical species had decreased in the tropics. These changes have negative implications for coastal fisheries in tropical developing countries, which tend to be particularly vulnerable to climate change (Cheung et al., 2013; Sections 6.4.3, 7.5.1.1.2).

There is considerably less information available on climate change impacts on fisheries and fishery resources in freshwater systems and aquaculture. Considerable attention has been given to the impacts of climate change in some African lakes but with mixed interpretations (Section 22.3.3.1.4). There is evidence that increasing temperature has reduced the primary productivity of Lake Tanganyika in East Africa and a study by O'Reilly et al. (2003) estimated that this would have led to a decrease of approximately 30% in fish yields. However, Sarvala et al. (2006) disagreed and concluded that observed decreases in the fish catches could be explained by changed fishery practices. There has been a similar difference of opinion for Lake Kariba, where Ndebele-Murisa et al. (2011) argued that a reduction in fisheries productivity had been caused by climate change while Marshall (2012) argued that the declines in fish catches can only have been caused by fishing. There is *medium confidence* that, in India, changes in a number of climate variables including an increase in air temperature, regional monsoon variation, and a regional increase in incidence of severe storms have led to changes in species composition in the River Ganga and to have reduced the availability of fish spawn for aquaculture in the river Ganga while having positive impacts on aquaculture on the plains through bringing forward and extending the breeding period of the majors carps (Vass et al., 2009).

Frequently Asked Questions

FAQ 7.1 | What factors determine food security and does low food production necessarily lead to food insecurity?

Observed data and many studies indicate that a warming climate has a negative effect on crop production and generally reduces yields of staple cereals such as wheat, rice, and maize, which, however, differ between regions and latitudes. Elevated CO_2 could benefit crops yields in the short term by increasing photosynthesis rates; however, there is big uncertainty in the magnitude of the CO_2 effect and the significance of interactions with other factors. Climate change will affect fisheries and aquaculture through gradual warming, ocean acidification, and changes in the frequency, intensity, and location of extreme events. Other aspects of the food chain are also sensitive to climate but such impacts are much less well known. Climate-related disasters are among the main drivers of food insecurity, both in the aftermath of a disaster and in the long run. Drought is a major driver of food insecurity, and contributes to a negative impact on nutrition. Floods and tropical storms also affect food security by destroying livelihood assets. The relationship between climate change and food production depends to a large degree on when and which adaptation actions are taken. Other links in the food chain from production to consumption are sensitive to climate but such impacts are much less well known.

7.2.1.3. Livestock Production

In comparison to crop and fish production, considerably less work has been published on observed impacts for other food production systems, such as livestock or aquaculture, and to our knowledge nothing has been published for hunting or collection of wild foods other than for capture fisheries. The relative lack of evidence reflects a lack of study in this topic, but not necessarily a lack of real-world impacts of observed climate trends. A study of blue-tongue virus, an important ruminant disease, evaluated the effects of past and future climate trends on transmission risk, and concluded that climate changes have facilitated the recent and rapid spread of the virus into Europe (Guis et al., 2012). Ticks that carry zoonotic diseases have also *likely* changed distribution as a consequence of past climate trends (Section 23.4.2).

7.2.2. Food Security and Food Prices

Food production is an important aspect of food security (Section 7.1), and the evidence that climate change has affected food production implies some effect on food security. Yet quantifying this effect is an extremely difficult task, requiring assumptions about the many non-climate factors that interact with climate to determine food security. There is thus limited direct evidence that unambiguously links climate change to impacts on food security.

One important aspect of food security is the prices of internationally traded food commodities (Section 7.1.3). These prices reflect the overall balance of supply and demand, and the accessibility of food for consumers integrated with regional to global markets. Although food prices gradually declined for most of the 20th century (FAO, 2009b) since AR4 there have been several periods of rapid increases in international food prices (Figure 7-3). A major factor in recent price changes has been increased crop demand, notably via increased use in biofuel production related both to energy policy mandates and oil price fluctuations (Roberts and Schlenker, 2010; Mueller et al., 2011; Wright, 2011). Yet fluctuations and trends in food production are also widely believed to have played a role in recent price changes, with recent price spikes often following climate extremes in major producers (Figure 7-3). Moreover, some of these extreme events have become more likely as a result of climate trends (Table 18-3). Domestic policy reactions can also amplify international price responses to weather events, as was the case with export bans announced by several countries since 2007 (FAO, 2008). In a study of global production responses to climate trends (Lobell et al., 2011a) estimated a price increase of 19% due to the impacts of temperature and precipitation trends on supply, or an increase of 6% once the beneficial yield effects of increased CO_2 over the study period were considered. Because the price models were developed for a period ending in 2003, these estimates do not account for the policy responses witnessed in recent years which have amplified the price responses to weather.

7.3. Assessing Impacts, Vulnerabilities, and Risks

7.3.1. Methods and Associated Uncertainties

7.3.1.1. Assessing Impacts

Methods developed or extended since AR4 have resulted in more robust statements on climate impacts, both in the literature and in Section 7.3.2. Two particular areas, which are explored below, are improved quantification and presentation of uncertainty; and greater use of historical empirical evidence of the relationship between climate and food production.

The methods used for field and controlled environment experiments remain similar to those at the time of AR4. There has been a greater use of remote sensing and geographic information systems for assessing temporal and spatial changes in land use, particularly in agricultural land use for assessment of food security status (Thenkabail et al., 2009;