November 2007

Citrus Canker Peer Review

Final Report

Prepared for

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U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Policy and Program Development Planning, Evaluation, and Monitoring
4700 River Road
Riverdale, MD 20737

Prepared by

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Health, Social, and Economics Research
Research Triangle Park, NC 27709

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Contents

Table

Executive Summary

The Office of Management and Budget (OMB) requires a peer review for important scientific information to ensure the quality of scientific and technical research and guide improvements in draft scientific documents before federal agencies disseminate them (OMB, 2004). The Animal and Plant Health Inspection Service (APHIS) is interested in conducting a peer review of the document *Movement of Commercially Packed Citrus Fruit from Citrus Canker Disease Quarantine Area.* This document identifies and evaluates options for regulating the interstate movement of fresh citrus fruit with the goal of reducing the potential for *Xanthomonas axonopodis* pv. *citri* (Xac) introduction and spread. APHIS requested RTI International's support for conducting a peer review conforming to OMB's guidelines (OMB, 2002; 2004) under their task order contract (AG-6395-C-07-0046, Task 1).

RTI conducted the peer review according to the statement of work. We identified and selected three experts to review the citrus canker document:

- Mark C. Anderson, New Mexico State University—an expert in risk assessment
- Donald A. Cooksey, University of California at Riverside—an expert in phytobacteriology
- L.W. "Pete" Timmer, University of Florida Citrus Experiment Station—an expert in plant pathology

The reviews are included as Appendices A, B, and C.

The three reviewers agreed that the analysis presented in the document clearly characterizes the potential of commercially packed citrus fruit as a pathway for the introduction and spread of citrus canker. Each reviewer identified additional areas to

address in the analysis, for example, the impact of citrus leaf minor, the risk involved in movement of citrus canker by means other than commercially packed citrus fruit, and the implications of climatic differences in the potential susceptibility of other citrus-growing states to novel Xac infestations.

The three reviewers concurred that the methodology used was appropriate for the analysis and that important assumptions were identified and uncertainties clearly stated. The reviewers agreed that the document was generally well organized and clearly written. One reviewer offered suggestions for improving the organization of the document.

One of the reviewers offered several criticisms of the risk assessment, including the use of pseudo-perspective graphs to present some of the results of the analysis and the lack of information on the pros and cons of the different risk management options in light of the risk assessment modeling effort.

The three reviewers think that the five risk management options presented were logical ones to consider given the evidence available. Each reviewer also commented on the logic behind the choice (or rejection) of the five risk management options.

1 Background and Objective

RTI International coordinated an external peer review of the document *Movement of Commercially Packed Citrus Fruit from Citrus Canker Disease Quarantine Area,* as requested by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) under task order contract AG-6395-C-07-0046, Task 1. The scientific document describes the effectiveness of potential measures to prevent the spread of citrus diseases from the state of Florida to other citrus-producing regions. In this report, we present background information about the peer review, describe the review process, list key questions or the charge to the reviewers, and include the three peer review reports.

The document under review evaluated available evidence regarding the biology and epidemiology of *Xanthomonas axonopodis* pv. *citri* (Xac) and the management of citrus canker disease and determined that the introduction of Xac through the movement of commercially packed fresh citrus fruit is unlikely. The evidence is not currently sufficient to conclude that fresh citrus fruit produced in a Xac-infested grove absolutely cannot serve as a pathway for introducing Xac into new areas. Furthermore, it is not possible to design an operationally feasible system that ensures only uninfected fruit moves from quarantined areas. Resource constraints and other practical considerations make it difficult to implement a grove-centered regulatory systems approach in Florida, so the analysis evaluated several packinghouse-centered risk management options for the interstate movement of fresh commercially packed citrus fruit from regions with citrus canker

disease to regions without the disease. Options include the following:

- Option 1—Allow unrestricted distribution of all types and varieties of *commercially packed* citrus fruit to all U.S. States.
- Option 2—Allow distribution of all types and varieties of *commercially packed* citrus fruit to all U.S. States, subject to packinghouse treatment with APHIS-approved disinfectant and APHIS inspection of finished fruit.
- Option 3—Allow distribution of all types and varieties of *commercially packed* citrus fruit (except tangerines) in U.S. States except U.S. commercial citrus producing States. Allow distribution of *commercially packed* tangerines to all U.S. States including commercial citrus-producing States. Require packinghouse treatment of all such citrus fruit with APHIS-approved disinfectant and APHIS inspection of finished fruit (all types and varieties) for citrus canker disease symptoms.
- Option 4—Allow distribution of all types and varieties of *commercially packed* citrus fruit in U.S. States except U.S. commercial citrus-producing States and require packinghouse treatment of citrus fruit with APHIS-approved disinfectant and APHIS inspection of finished fruit.
- Option 5—Leave the current regulations for the interstate movement of citrus fruit from citrus canker quarantined areas in place and unchanged.

The analysis conducted by APHIS is scientifically important and thus warrants an external peer review as per the Office of Management and Budget (OMB) (2004) guidelines. Peer review is an important process that can help ensure that the quality of scientific information meets the standards of the technical community, and it can help strengthen and clarify the analysis. APHIS requested RTI's support in conducting a formal and independent peer review conforming to OMB's guidelines for peer review and quality of information (OMB, 2002; 2004).

2 Description of Review Process

RTI conducted the review process in accordance with OMB's guidelines (OMB, 2004). The review process consisted of selecting the reviewers, explaining the scope of the review, facilitating the review, and consolidating the reviews in a single report.

First, we selected three peer reviewers based on their expertise. We initially identified 20 potentially suitable reviewers after understanding the background and objectives of the peer review from APHIS. Subsequently, we finalized the list to three reviewers based on their availability and the desired overlap of expertise in the areas of risk assessment, plant pathology, and phytobacteriology. We also considered conflict of interest in the selection process.

We selected the following individuals to peer review the document:

- Mark C. Anderson, New Mexico State University—an expert in risk assessment
- Donald A. Cooksey, University of California at Riverside—an expert in phytobacteriology
- L.W. "Pete" Timmer, University of Florida Citrus Experiment Station—an expert in plant pathology

Table 2-1 provides a brief description of each of the three peer reviewers.

Table 2-1. Peer Reviewers' Summary of Experience

Mark C. Andersen *Professor* *Department of Fishery and Wildlife Sciences, New Mexico State University (NMSU)* Dr. Andersen teaches ecological modeling and wildlife science in the undergraduate and graduate programs at NMSU and maintains an active research program. Major focuses for his professional and research activities include risk analysis of invasive species, development of ecological population models, analysis of data related to wildlife populations, and management decisions related to wildlife conservation. Dr. Andersen serves as a peer reviewer for several professional publications, including *Ecology*, *Journal of Mathematical Biology*, *Journal of Wildlife Management*, and *Journal of Arid Environments* (international). He is an active member of the Ecological Society of America and the Society for Risk Analysis. Dr. Andersen served on the faculty at the University of California at Irvine for 6 years before joining the faculty at NMSU in 1994. He received baccalaureate and master's degrees in environmental biology from California State University at Fresno and a second master's degree in biomathematics from the University of Washington. He also received his doctorate from the University of Washington, studying population ecology. He is an author on more than 34 peer-reviewed scientific publications in addition to several book reviews.
Donald A. Cooksey *Interim Dean* *College of Natural and Agricultural Sciences, University of California at Riverside (UCR)* In addition to his duties as dean, Dr. Cooksey is a Professor and Bacteriologist in the Department of Plant Pathology at UCR. Other positions previously held by Dr. Cooksey include Associate Dean for the UCR Agricultural Experiment Station and Cooperative Extension, Department Chair for UCR's Plant Pathology Department, and Faculty Assistant in the University of California's Office of the President. His research focus is on bacterial diseases of plants, concentrating on the diagnosis, strain identification, phylogeny, genomics, and biological control of *Xylella fastidiosa* and the cause of Pierce's disease of grapevines and other economically important crops. Dr. Cooksey has led the grant review committee for several state commodity boards, including citrus. He is involved with numerous national and international organizations, including USAID, USDA-NRI, and the American Phytopathological Society. He received his baccalaureate degree in biology from Albion College and doctorate in botany and plant pathology from Oregon State University. He is an author on more than 50 peer-reviewed scientific publications.
L.W. "Pete" Timmer *Distinguished Professor* *Citrus Research and Education Center, University of Florida* Dr. Timmer is recognized internationally for his research on citrus diseases and fungicides, presenting at meetings in Spain, Brazil, South Africa, and Mexico. Dr. Timmer has taken numerous research sabbaticals to Argentina, Australia, and the University of California at Davis to study citrus canker and other citrus diseases. He has been involved in state, national, and international professional organizations, serving as Senior Editor for the American Phytopathological Society, President of the Florida Phytopathological Society, and Editor and Secretary of the International Organization of Citrus Virologists. Dr. Timmer received his baccalaureate degree in botany and plant pathology from Michigan State University and his doctorate in plant pathology from the University of California at Riverside. In the past 5 years, he has been an author on more than 34 peer-reviewed scientific publications in addition to several book chapters.

Second, we explained the scope of the review in terms of the charge to the reviewers prepared by APHIS. RTI provided the charge to the reviewers, asking them to provide potential solutions to address their comments. The charge consists of nine questions as described in Section 3.

Third, RTI communicated and clarified any questions the reviewers had about the scope of the review or the document itself. We communicated the progress and status of the review to APHIS regularly and ensured that the reviewers were meeting the objectives of the peer review. We also ensured that the reviewers describe possible ways to address their concerns instead of only describing the concerns.

Finally, we compiled the three reviews in a single report. We include the original peer reviews as Appendices A, B, and C. To maintain the integrity of the reviews, we present the reviews as appendices to this report instead of consolidating the comments by the charge questions. Each reviewer focused on different aspects of the charge questions depending on his area of expertise, and their reporting formats and writing styles also differ. Therefore, reading each review separately can help readers better understand their comments. We have corrected minor typographical errors and slightly reformatted their reports to ensure a minimum level of uniformity of presentation in this report.

3 Charge to the Peer Reviewers

APHIS asked the reviewers to focus and structure their reviews on the specific questions listed below.[1]

1. Does the analysis clearly characterize the potential, or lack thereof, for commercially packed citrus fruit to serve as a pathway for the introduction and/or spread of *Xanthomonas axonopodis* pv. *citri*?
2. Are the data or other evidence complete? If not, please indicate significant references that should be included.
3. Does the analysis accurately characterize the cited literature?
4. With regard to the methodology, is the approach and process appropriate for the analysis?
5. Are all important assumptions identified and uncertainties clearly stated?
6. Is any part of the document difficult to read or understand?
7. Were the quantitative methodologies used in this assessment applied appropriately to achieve the objectives of the inspection efficacy assessments?
8. Do the data and the evidence support the range of risk management options presented?
9. Is the logic behind the choice (or rejection) of risk management options clearly stated and supported by data and evidence presented?

[1]The reviewers also provided general comments that can inform the nine specific questions. However, they kept the general comments separate from the specific questions as per RTI's request.

References

The Office of Management and Budget (OMB). 2002. "Information Quality Guidelines." The Office of Information and Regulatory Affairs, the Office of Management and Budget, the Executive Office of the President, Washington, DC. October 1, 2002.

The Office of Management and Budget (OMB). 2004. "Final Information Quality Bulletin for Peer Review." A Memorandum for Heads of Departments and Agencies. M-05-03. The Office of Management and Budget, the Executive Office of the President, Washington, DC. December 16, 2004.

Appendix A:
Review #1

Review of USDA-APHIS Document:

"Movement of Commercially Packed Citrus Fruit from Citrus Canker Disease Quarantine Area"

Summary Evaluation

The document prepared by APHIS is very well done, logically presented, and is easy to follow. It provides thorough coverage of the biology of *Xanthomonas axonopodis pv. citri* (Xac) and citrus canker disease as well as the assessment of the risks involved in movement of fruit from canker-infested areas. I concur that commercially packed fresh fruit cannot be completely eliminated as a potential source for infestation of unaffected citrus areas. Nor would it be reasonable to expect that movement of fruit from infested areas could be accomplished while at the same time eliminating all risk of transmission of the disease.

In my opinion, the analysis clearly characterizes the potential of commercially packed citrus fruit as a pathway for the introduction and spread of citrus canker. However, I feel that the importance of commercial fruit as a means of introduction is not put into proper perspective in relation to other possible means by which canker could be introduced into new areas that represent much greater risks. Most of the relevant information has been presented and I know of no references of major importance that have not been included. I am not an expert in risk analysis, but that presentation appears to be logical and appropriate. The proper assumptions have been identified and the analysis seems to achieve the objectives laid out. The risk management options are clearly stated and supported by the evidence presented.

1. **Does the analysis clearly characterize the potential, or lack thereof, for commercially packed citrus fruit to serve as a pathway for the introduction and/or spread of *Xanthomonas axonopodis pv. citri*?**

For the most part, I think the potential of commercial fruit as a pathway for introduction of canker is appropriately characterized. However, in my opinion, the potential importance of epiphytic populations that might remain on the surface of fruit outside of lesions is given an inordinate amount of importance. I realize that this is due to the fact that

opponents of movement of commercial fruit have used the survival of a few bacteria on the fruit surface to prove that all risk cannot be eliminated. However, I think the skills of any plant pathologist would be challenged if they were asked to successfully inoculate and infect citrus plants from bacteria with that source alone. In the absence of visible lesions on fruit and assuming that normal packinghouse procedures were followed, it would be extremely unlikely that enough bacteria would remain by the time the fruit arrived at market to infect a citrus plant. The really important point that is well covered is that Xac is casual rather than a resident epiphyte and does not multiply outside of lesions.

2. Are the data or other evidence complete? If not, please indicate significant references that should be included.

The only area that has not been addressed that seems to me to be relevant is the risk involved in movement of citrus canker by means other than commercially packed fruit. Canker can be moved on living plant material, on fruit, budwood, and vegetative materials brought in by growers, nurserymen, hobbyists and tourists illegally and those means of entry are the most likely method for introduction of canker and most other exotic diseases. While I realize that such risks are not easily quantifiable, some idea could be developed from interceptions at ports of entry. Nearly everyone agrees that the risk represented by commercial fruit is minimal. However, the fact remains that no matter how low the risk, if enough fruit is moved over enough years, eventually the disease will be introduced and established to the extent permitted by the local climate in all citrus areas.

Thus, I think that the important point is that the disease is far more likely to be introduced by other means and that commercial fruit is among the least probable means of introduction. My feeling is that by exercising control over commercial fruit that we are expending a large amount of time, energy, and funds to control a relatively minor portion of the risk. Some effort is being made to reduce illegal introduction through ports of entry, but the fact is that many introductions escape detection. Total risk would be reduced much more by stricter enforcement of illegal introductions of infected propagative material and fruit than by control of movement of

commercial fruit. I realize this document deals with movement of commercial fruit, but addressing other means of movement would have put the risk involved in movement of commercial fruit in proper perspective.

3. Does the analysis accurately characterize the cited literature?

Virtually all of the relevant publications are covered in the review and listed in the Literature Cited. Perhaps, there is insufficient differentiation of complete studies with repeated experiments published in refereed journals compared to those reports of single experiments published in nonrefereed journals or popular magazines. Most of the quotes used, however, as far as I was able to determine accurately reflect the results of studies or the opinions of the authors.

A few specific comments:

One point that should be included in the document is that the windbreak study by Gottwald and Timmer (1995) was carried out under nursery rather than grove conditions.

Documentation should be provided for the statement that bacteria are killed when placed in an acid environment (p.19).

Another point that could be made is that waxing of fruit coats any lesions present with a hydrophobic material that prevents penetration of water which would greatly limit exudation of bacteria from canker lesions and reduce risk from such sources. I know of no references to document that statement, but it seems like a reasonable point given what is known about inoculum release from lesions.

There are several phases required to establish an exotic disease in a new area. The introduction phase is covered in detail and the establishment phase is well addressed. However, there is perhaps inadequate coverage of the subsequent spread and establishment of the disease and the development of a disease problem. As pointed out in the document, canker has been introduced into arid areas such as Yemen and Saudi Arabia and become established. However, unless favorable conditions such as frequent overhead irrigation are created artificially to promote canker reproduction and spread, the disease would never become a problem.

4. With regard to the methodology, is the approach and process appropriate for the analysis?

In my opinion, the approach and the process used are appropriate for the analysis.

5. Are all important assumptions identified and uncertainties clearly stated?

All of the assumptions made have been clearly identified and any uncertainties have been brought out.

6. Is any part of the document difficult to read or understand?

In my opinion, the document was very well prepared and quite complete with the exception noted above. In no case did I have any difficulty in following the presentation or the arguments.

7. Were the quantitative methodologies used in this assessment applied appropriately to achieve the objectives of the inspection efficacy assessments?

I do not specialize in risk assessment and thus, I am unfamiliar with all the techniques and approaches used. However, it appears that the methodology used is logical and the conclusions drawn are reasonable.

8. Do the data and the evidence support the range of risk management options presented?

The evidence presented support the range of options for management of risk. My opinion of each of those options is presented in the last section of the review.

9. Is the logic behind the choice (or rejection) of risk management options clearly stated and supported by data and evidence presented?

In my opinion, the management options are clearly stated and the risks involved in each are properly portrayed except as noted above. My opinion of those options is presented below.

Option 1: Allow unrestricted distribution of all types and varieties of commercially packed citrus fruit to all U.S. States.

As mentioned above, I do not believe commercial fruit comprises a large percentage of the risk of introduction. Thus,

even if fruit distribution were unrestricted, I do not feel it would greatly increase total risk. Commercial fruit is heavily graded to remove any blemished fruit, not only for disease control purposes, but also for cosmetic reasons. Thus, most fruit with canker lesions would be graded out in any case. As pointed out in the document, lesions on mature fruit are old and produce relatively small amounts of inoculum and I consider any epiphytic bacteria present to be an extremely remote possibility as a source of inoculum. From a strictly pathological point of view, removing all restrictions of commercial fruit would not greatly increase the total risk of introduction of canker into new areas for reasons stated above. Controlling 1% of the risk more effectively does not diminish the total risk of introduction greatly.

Option 2: Allow distribution of all types and varieties of commercially packed citrus fruit to all U.S. States, subject to packinghouse treatment with APHIS-approved disinfectant and APHIS inspection of finished fruit for citrus canker disease symptoms.

I support this option as being prudent and realistic. Any commercial fruit shipped to citrus-producing states is unlikely to result in the introduction of the disease into those states. Currently, there is no effort being made to limit the movement of illegal living citrus plants between states. Thus, the most likely means of introduction would be by that means or possibly by illegal movement of uninspected and untreated fruit. Eliminating shipments of fruit to citrus-producing states would not greatly reduce the potential movement of the disease. In addition, it is highly unlikely that canker would become established and become a production problem in California or Arizona. Even though the possibility would be greater for Texas, I doubt that canker would be a serious problem even there. Canker could be serious in Louisiana, but introduction there is much more likely on living plants moved from Florida than on commercial fruit.

Option 3: Allow distribution of all types and varieties of commercially packed citrus fruit (except tangerines) in U.S. States except U.S. commercial citrus producing States. Allow distribution of commercially packed tangerines to all U.S. States including commercial citrus-producing States. Require packinghouse treatment of all such citrus fruit with APHIS-approved disinfectant and APHIS inspection of finished fruit (all types and varieties) for citrus canker disease symptoms.

This option represents a very minor difference in risk from the previous one. Obviously, restricting movement of fruit to citrus-producing states to tangerines would reduce the amount of fruit moved and in that sense lower risk. However, with regard to the type of citrus fruit moved, risks with tangerines might be less than with a highly susceptible type such as grapefruit. However, the difference between tangerines and some of the more tolerant oranges, such as Valencias, would be minute. From my perspective, this option would be complex to implement and represent very minimal gain in terms of reducing risk.

Option 4: Allow distribution of all types and varieties of commercially packed citrus fruit in U.S. States except U.S. commercial citrus-producing States and require packinghouse treatment of citrus fruit with APHIS-approved disinfectant and APHIS inspection of finished fruit.

As pointed out above, I think restricting movement to non-citrus states reduces risk relatively little. Since there is no control exercised over illegal movement of citrus vegetative material or fruit, restriction of movement of commercial fruit to citrus-producing states accomplishes little.

Option 5: Leave the current regulations for the interstate movement of citrus fruit from citrus canker disease quarantined areas in place and unchanged.

In my opinion, it is difficult to support this option. Eventually most or all Florida citrus groves will be infested with canker and such a rule would, for all practical purposes, eliminate production of fresh fruit in Florida. The economic impact of such a decision would be great and the impact in terms of reducing risks to other citrus states would be minimal.

However, that being the case, there is no justification for restriction of imports of fresh fruit from international sources where canker is present. That certainly will have a great impact

of the movement of fresh fruit and allow a great deal of competition from other countries with uncertain consequences.

Appendix B:
Review #2

Review of USDA-APHIS Document:

"Movement of Commercially Packed Citrus Fruit from Citrus Canker Disease Quarantine Area"

1. **Does the analysis clearly characterize the potential, or lack thereof, for commercially packed citrus fruit to serve as a pathway for the introduction and/or spread of *Xanthomonas axonopodis* pv. *citri*?**

Yes, for the most part, the document contains a very thorough and unbiased analysis of existing data on the potential for citrus fruit to serve as a pathway for introduction of Xac. The document is well organized to address this issue, through the identification (on page 7) of six main reasons why previous analyses (USDA 1995; Shubert et al., 1999b; USDA 2006) have concluded that there is a low likelihood of introducing citrus canker through movement of fruit. Each of these six reasons is analyzed in detail, followed by summaries for each of the reasons, with conclusions related to the likelihood of Xac being found on fruit, surviving fruit inspection, cleaning, disinfection, and storage, as well as the likelihood of inoculum on fruit encountering favorable environmental conditions and susceptible hosts.

Most of the analysis supports the idea that spread and establishment of citrus canker through movement of fruit is unlikely, but it also accurately recognizes that the bacterium can be found on citrus fruit and could be carried to other states on infested fruit. Therefore, the authors conclude logically that this mode of transmission can not be ruled out completely. In addition, a quantitative model was developed (Appendix 1) to determine the potential quantity of symptomatic fruit shipped from Florida to other citrus-producing states. That model indicated that there is a potential for symptomatic fruit to be shipped to other citrus-producing states, even with APHIS-approved disinfectant treatments and mandatory packinghouse phytosanitary inspections.

2. Are the data or other evidence complete? If not, please indicate significant references that should be included.

In general, the document is very complete in analyzing data that exists in the literature. One topic that that was not covered as thoroughly as it might have been was the subject of the citrus leaf miner. As mentioned on pages 6 and 9, the citrus leaf miner can provide wounds for infection by Xac, and leaf miner wounds create a suitable microclimate for Xac multiplication. In addition, it is pointed out that even highly resistant cultivars and species of citrus can be infected by Xac if leaf miner is present. However, the influence of the leaf miner is not brought up again in the discussion of Sections 5.4 and 5.5 on environmental conditions required for Xac establishment and host resistance. It is concluded (page 21 Summary) that for citrus canker to establish in another citrus-producing state, Xac must encounter an environment with a temperature, relative humidity, and rain events that are conducive to infection. While Florida-like environmental conditions are not common in most of California, are such conditions necessary if the leaf miner is common? Leaf miner populations have increased considerably in recent years in southern and central California (although low this year, probably due to a series of hard freezes this past winter). Leaf miner damage also results in lower inoculum thresholds being required for infection (*Crop Protection*, 2007, 26:59-65). Xac can infect through leaf miner wounds at considerably lower inoculum levels (as low as 10^1 cfu/ml) than the levels discussed on page 20 of the analysis document. Thus, the conclusion based on review of the literature, in both the Executive Summary (page i, 3rd bullet) and on page 21, may need to be modified, if it is true that significant levels of leaf miner could negate the requirement for Florida-like environmental conditions.

Another consideration that is not mentioned is the citrus peel miner (*Marmara gulosa*), which is a problem sporadically in central California. I am not familiar with any literature addressing whether damage to the fruit from the peel miner can make citrus fruit more susceptible to Xac infection, but this seems like another factor to consider in assessing whether citrus canker infections are possible to occur in more arid states.

3. Does the analysis accurately characterize the cited literature?

Yes, the literature reviewed in the document is a comprehensive collection of relevant literature on citrus canker, and of those articles with which I was previously familiar, or read in the course of my review of the document, the analysis accurately characterizes their content and conclusions. I suggest adding the article on leaf miner damage mentioned above that appeared in *Crop Protection* just recently.

4. With regard to the methodology, is the approach and process appropriate for the analysis?

Yes, the general approach of discussing the six main reasons why previous analyses have concluded that there is a low likelihood of introducing citrus canker through movement of fruit is appropriate. That discussion then formed the basis for accepting or rejecting the five different risk management options, which was a logical approach. I liked the addition of the quantitative model (Appendix 1) to determine the potential quantity of symptomatic fruit shipped from Florida to other citrus-producing states. I am not qualified to judge the statistical accuracy of the model, but I was able to follow the logic of its development and found it to be an appropriate approach to help answer this risk assessment question. It is based on real statistics of the amount of fruit shipped to citrus-producing states, as well as data on the accuracy of inspection protocols.

5. Are all important assumptions identified and uncertainties clearly stated?

Yes, the document does a good job of identifying where assumptions are made, based on lack of data, and limitations in specific steps due to uncertainties are identified.

6. Is any part of the document difficult to read or understand?

The document is generally very well organized and clearly written. To improve it, I would suggest organizing Section 5 to more closely reflect the wording that is used on page 7 for the six main reasons why previous analyses have concluded that there is a low likelihood of introducing citrus canker through movement of fruit. The same wording for each numbered

reason should be copied and used as the headings for the subsections in Section 5, just as one would do with the objectives of a grant proposal and their subsequent use as headings in the experimental section of a proposal. The worst way to write a grant proposal is to present a list of objectives, and then in the experimental section, use headings that reword or change the objectives. Section 5 seemed a little bit like that.

The discussion of the quantitative model (Appendix 1) probably should be brought into an earlier section of the document, rather than waiting until the discussion of risk management option 2 on page 31. The findings of the model are relevant to the discussion of phytosanitary inspection in Section 5.2. There it is concluded (on page 17) that "grading and inspection procedures are effective in removing fruit with visible lesions." However, the model in Appendix 1 concludes that there is potential for symptomatic fruit to be shipped to citrus-producing states, even with inspection procedures in place. It would be better to discuss the model results in Section 5.2, and again in Section 6 (page 27), where a conclusion is made that "APHIS concludes that a phytosanitary inspection at the packinghouse is an effective measure to detect fruit with Xac symptoms and reduce the likelihood that fruit with symptoms are shipped." That may be true, but the model in Appendix 1 suggests that some symptomatic fruit will likely still get through and be shipped. As it is, this leaves conflicting conclusions in different parts of the document. Even the Executive Summary starts out with five bulleted conclusions (page i) that appear to be in conflict with the predictions of the model. I recommend discussing the model and its findings within Section 5 and modifying the conclusions there and in the executive summary to be consistent with those expressed in discussion of the model, as in Section 7.2.

7. Were the quantitative methodologies used in this assessment applied appropriately to achieve the objectives of the inspection efficacy assessments?

Yes, as stated above, the quantitative model in Appendix 1 seemed like an appropriate approach to address the risk assessment question of whether symptomatic fruit could be shipped from Florida to other citrus-producing states, even with phytosanitary inspection procedures in place, although I am not qualified to judge the statistical accuracy of the model.

8. Do the data and the evidence support the range of risk management options presented?

Yes, I think the five risk management options are logical ones to consider, based on the discussion of previous risk assessment analyses and data from the literature in Section 5.

9. Is the logic behind the choice (or rejection) of risk management options clearly stated and supported by data and evidence presented?

Yes, for Options 1–3. However, the logic presented for rejecting Options 1–3 would seem to apply to Option 4. The analysis of existing literature concludes that evidence is not currently sufficient to prove that infected fruit cannot possibly serve as a pathway for the introduction of Xac, and the quantitative analysis in Appendix 1 estimates that symptomatic fruit may be shipped from Florida to other states. On page 35, it is stated that "APHIS staff cannot estimate the frequency of unreported illegal movement of Florida citrus to citrus-producing states or the proportion of reported illegal movement to total illegal movement." Using the logic applied to Options 1–3, this uncertainty means that APHIS can not rule out that infected fruit could reach citrus-producing states through illegal movement of citrus from non-citrus producing states. In accepting Option 4, the document states (page 35) that "Option 4 compensates for uncertainty in the rate of illegal fruit movement by requiring a disinfectant treatment and phytosanitary inspection in addition to the distribution restriction." This is no different from what Option 2 requires (disinfectant treatment and phytosanitary inspection), but Option 2 was rejected based on the prediction from the Appendix 1 model that in spite of the treatments and inspections, there is potential for infected fruit to be shipped out of Florida. Unless I missed something, Option 4 presents no additional mitigation to assure that infected fruit will not be shipped out of Florida than Option 2 does. The only difference is that under Option 4, movement to a citrus-producing state would have to occur by illegal shipping, which does make it less likely to occur than under Option 2, where infected fruit could be shipped directly (legally) to citrus-producing states. However, APHIS says they can not quantify the frequency of such illegal shipments, so they have no quantitative reason to reject this as a possibility. What if infected fruit is legally

shipped to Nevada, for example? It is not unreasonable to think that illegal shipments could occur from there into citrus-producing areas of California. My recommendation is that the analysis should reject Option 4 with the same logic as used to reject the other options.

Appendix C:
Review #3

Review of USDA-APHIS Document:

"Movement of Commercially Packed Citrus Fruit from Citrus Canker Disease Quarantine Area"

Introduction—History and Background

There have been a few different outbreaks of citrus canker (a disease caused by Xanthomonas axonopodis pv. citri, or Xac for short) in citrus-producing regions of the United States. The earliest began around 1910 and was eradicated by 1943; the second began in the mid-1990's and was declared eradicated in 1994. Unfortunately, eradication, unlike extinction, is not forever, and the disease reappeared in Florida in 1995, leading to resumption of eradication efforts. In response to the hurricane seasons of 2004 and 2005, the USDA recognized that eradication was no longer a feasible goal, and put the entire state of Florida under quarantine. The document I was asked to review represents a shift in USDA's focus from controlling citrus canker at the level of individual groves to controlling it at the level of the individual packinghouse, and summarizes available evidence concerning the likelihood of establishment of new citrus canker infestations outside of Florida in the other five citrus-producing states (Hawaii, California, Arizona, Texas, and Louisiana) due to transport of commercially-packed fresh Florida citrus fruit. The document also uses a pathway-based probabilistic risk assessment to examine five different proposed regulatory scenarios. Although I reviewed the entire document, the bulk of my critique will be focused on this probabilistic risk assessment. I have formatted my review as answers to a set of questions posed in the peer review notice and guidelines.

1. Does the analysis clearly characterize the potential, or lack thereof, for commercially packed citrus fruit to serve as a pathway for the introduction and/or spread of *Xanthomonas axonopodis* pv. *citri*?

The main conclusion of the document, based on a qualitative risk assessment, is that the likelihood of introducing Xac into previously canker-free areas via transport of commercially-packed citrus fruit is extremely low. Several lines of evidence converge to support this conclusion.

1. Existing agricultural practices, including field spraying, culling, and decontamination of harvesting equipment,

as well as other factors such as decreasing plant tissue susceptibility to wounds and infection with fruit maturation, and low survival of epiphytic pathogens, tend to lead to low per-grove levels of infestation. In addition, most infected fruit are likely to be clearly symptomatic and thus readily recognized and culled.

2. Culling and treatment practices, as well as APHIS inspections, are effective at identifying and isolating infected fruit at packing houses. Grading and inspection remove most (but not all) symptomatic fruit, and disinfection kills nearly all Xac on asymptomatic fruit.
3. Typical citrus shipping and storage conditions are likely to lead to high mortality of any remaining epiphytic Xac on commercially packed fruit.
4. Establishment of new Xac infestations from shipped fruit is highly unlikely, and would depend on a practically unknowable sequence of unlikely events. Xac in sufficient amounts to establish a new local population would need to encounter appropriate conditions of temperature, humidity, and precipitation timing. These pathogen inocula would also need to encounter and infect host plant tissue that is either wounded or at an appropriate growth stage.
5. Tangerines, while somewhat resistant to citrus canker infection, are by no means immune to it.
6. In those few cases where the origins of new citrus canker outbreaks are known or at least strongly suspected, nursery stock has been the culprit. There are no known cases of establishment of new citrus canker outbreaks from fresh fruit, rinds, or seeds.

In general, except as noted in my answer to question (2) below, I found these arguments convincing and well-supported by the data.

2. Are the data or other evidence complete? If not, please indicate significant references that should be included.

Although I agree that the required sequence of events is unlikely, I'm not yet convinced that sufficient thought has been given to potential pathways for establishment of Xac in previously canker-free areas due (perhaps indirectly) to transport of commercially-packed fruit. For example, rinds from commercially-packed fruit may be incorporated into compost, which may then come into contact with citrus trees, providing

another potential establishment pathway. (This example also shows how establishment pathways that are operationally defined as separate may actually intersect. I do not consider this omission a serious weakness in the document, because the qualitative risk assessment indicates that this pathway may be even less likely than establishment via direct contact with commercially-packed fruit. I only mention this possibility to show that there are many imaginable ways in which citrus canker might become established.) In the same vein, are organic citrus groves likely to be more at risk as potential establishment sites than conventionally-tended citrus groves? (Note that the choice of risk management Option 4 would make this possibility relatively unimportant.) I would like to have seen more on the implications of climatic differences in the potential susceptibility of the other citrus-growing states to novel Xac infestations, and the implications of these differences for the risk management options considered. (For example, could shipments to the other five citrus-producing states have been considered separately as non-mutually-exclusive risk management options?)

3. Does the analysis accurately characterize the cited literature?

Since I am not familiar with the literature on plant pathology in general, or on Xac in particular, I cannot comment on how accurately or completely the document characterizes the literature in that area. As far as the risk assessment is concerned, the literature the authors cite is appropriate to the methodology, and certainly reflects the current state of practice in such risk assessments. In addition to the literature resources, the authors use other methodological tools such as mathematical theorems and approximations, and software tools. These are also appropriate to the task and used in a justifiable way.

4. With regards to the methodology, are the approach and process appropriate for the analysis?

The purpose of the risk assessment and associated probability model is to estimate the number of symptomatic citrus fruit shipped from Florida to citrus-growing regions in the other five citrus-producing states (Arizona, California, Hawaii, Louisiana, and Texas). The model does not evaluate the likelihood of actual Xac establishment. The conceptual model for the risk

assessment is a four-node non-branching pathway model. This model has four parameters to be estimated from the available data. They are:

1. The number of cartons of Florida citrus fruit of all varieties shipped to other citrus-producing states per shipping season. This was modeled as a set of Pert distributions, one for each citrus type (oranges, lemons, etc.) for each of the five other citrus-producing states.
2. The number of fruit per carton for each citrus fruit type. This was modeled as a set of Pert distributions, one for each citrus fruit type.
3. The proportion of all fruit shipped that is Xac-symptomatic. The authors use a very nice probability argument to show that this proportion is a beta-distributed random variable (representing the apparent prevalence of symptomatic fruit) divided by a Pert-distributed random variable (representing the sensitivity of inspections). This is the core of the authors' argument in favor of a fixed inspection sample of 1,000 fruit per incoming lot, which seems quite reasonable and well-supported.
4. The proportion of Xac-symptomatic fruit shipped to citrus-growing regions of citrus-producing states. The authors go through some fairly complex calculations to try to account for both citrus-producing acreage within citrus-producing counties, and the populations of citrus-producing counties relative to the populations of the whole state. The model also accounts for both backyard fruit and commercially-grown fruit. The calculations seem quite reasonable.

The risk assessment calculations involve clever but standard applications of the central limit theorem and the Poisson approximation to the binomial distribution. The calculations were performed using standard software and yield results that are mostly intuitive and completely interpretable. The authors find that, at a constant sampling rate of 1,000 fruit per incoming lot, which is readily achievable with current APHIS staffing levels, at most a couple thousand symptomatic fruit would be reaching citrus-growing areas of citrus-producing states per shipping season, under risk management option 2, which permits distribution of all types and varieties of commercially packed citrus fruit from Florida to all U.S. states, subject to packinghouse disinfection and APHIS inspection.

5. Are all the important assumptions identified and uncertainties clearly stated?

The assumptions of the risk analysis are accurately and comprehensively stated on pp. 52-53. The authors do a good job of identifying remaining sources of uncertainty on p. 90; none of the major uncertainties seems to influence the validity of the overall conclusions.

6. Is any part of the document difficult to read or understand?

Even with a minimal background in plant pathology, I found the review of the literature on Xac and citrus production well-written, concise, and easy to follow. I have a much more extensive background in risk assessment and stochastic modeling; the sections of the document that dealt with these issues seemed logical and accurate to me, and were not difficult to understand.

7. Were the quantitative methodologies used in this assessment applied appropriately to achieve the objectives of the inspection efficacy assessments?

The document does a very thorough job of using the results of the risk assessment to justify the constant 1,000-fruit inspection sample advocated. Although not directly relevant to the stated aim of the risk assessment, this is, in my view, one of its most significant results. I have a couple of criticisms of the risk assessment.

1. The authors use graphs with a pseudo-perspective effect (Figures 9-11 through 9-15) to present some of their results. This goes against accepted practice for the design of effective data graphics. Pseudo-perspective bar charts such as Figure 9-12 make it difficult to reference the top of each bar against the y-axis; it is never clear for such graphs if it is the apparent front of the bar or the apparent back of the bar which represents the true height. Removing the pseudo-perspective, as in Figure 9-19 makes the graph less cluttered and more informative. Pseudo-perspective pie charts such as Figure 9-13 have even more severe problems. The foreshortening introduced by the pseudo-perspective effect makes it nearly visually impossible to relate the relative areas of the various slices of the pie to the actual percentages they are supposed to represent. These same results can be presented in a more

informative way in a simple pie chart, without any tilting or even in a table. The SYSTAT Graphics[1] manual provides a good introduction to the general topic of designing effective data graphics.

2. I would have liked to see more on the pros and cons of the different risk management options in light of the results of the risk assessment modeling effort. Option 1 was (rightly, I think) rejected due to the uncertain evidence concerning commercially-packaged citrus fruit as a pathway for introduction of citrus canker into new areas. The data presented and synthesized in the report, particularly in Section 5.5, effectively remove Option 3 from contention. Option 5's position is weakened by a clearly-presented feasibility argument. Although I agree that such arguments are crucially important in policy analyses, I would like to see more analysis to back up the statement that a "packinghouse-based inspection could ensure the same level of phytosanitary security as the current grove certification approach" (Section 7.5). Perhaps this analysis is in another document; still, any analysis comparing a grove-based strategy with a packinghouse-based strategy would have to reconcile that comparison with the discussion of uncertainty concerning the efficacy of grove inspections as compared to packinghouse culling on p. 90.

8. Do the data and the evidence support the range of risk management options presented?

In general, yes. However, as mentioned above in my answer to question (2), I would like to have seen some discussion of the how the climatic differences between the other five citrus-producing states might have influenced decisions to allow or prohibit shipments of commercially-packed citrus fruit to those states individually. On the other hand, perhaps the authors were required to consider only mutually-exclusive risk management options; if that's the case, this criticism is irrelevant.

[1] SYSTAT. 2004. SYSTAT 11 Graphics. SYSTAT Software Inc., Richmond CA. See also E.R. Tufte. 1983. The visual display of quantitative information. Graphics Press, Cheshire CT, and W.S. Cleveland. 1993. Visualizing data. Wadsworth, Monterey CA.

9. Is the logic behind the choice (or rejection) of risk management options clearly stated and supported by data and evidence presented?

In general, yes. Of the five risk management options considered, options 1 and 5 are either straw men or endpoints of the spectrum of possibilities, depending on one's point of view. Option 3 is excluded from further consideration because of the review of published data. This leaves options 2 and 4. Of these two options, option 4 is risk-averse, while option 2 implies tolerance for a very small, but essentially unknowable, risk. The risk assessment itself isn't really formulated in such a way as to allow us to choose between options 2 and 4. However, I consider this more a limitation of risk assessment in general than a limitation of this particular risk assessment.

Summary

In general, I agree with the main conclusion of the document that the likelihood of introducing Xac into previously canker-free areas via transport of commercially-packed citrus fruit is extremely low. I also agree that a quantitative estimate of this probability would be nearly impossible to calculate. I found the overall approach and the specific structure and computations of the risk assessment to be appropriate and defensible. The conclusions are well-supported by the data and the analyses.

However, I think the authors should still have put more effort into delineating possible pathways involving fresh fruit by which citrus canker might become established in previously canker-free areas. I think this kind of analysis would provide the following:

1. A starting point for possible future risk assessments.
2. An initial focus for (in my opinion badly-needed) public education efforts to help prevent citrus canker from establishing new infestations.
3. Possibly better ability to judge between risk management options 2 and 4.

This also seems to be the appropriate place to emphasize that the extension services of the other five citrus-growing states need to be producing and promoting a vigorous program of public education informing people of the danger, however small it may be, of citrus canker establishment in their area, and of things they can do to reduce the danger (like not discarding orange rinds from their lunch in a citrus grove). Although I

understand that this is outside the scope of the document I reviewed, I believe that it's worth mentioning.